Candidates for historical supernovae and their comparison against known Chinese records

Wilson, Graham Philip

CANDIDATES FOR HISTORICAL SUPERNOVAE AND THEIR COMPARISON AGAINST KNOWN CHINESE RECORDS

GRAHAM PHILIP WILSON

UNIVERSITY COLLEGE

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ABSTRACT

In this MSc thesis, possible/probable supernova remnants associated with possible/probable historical supernovae are discussed and advancements in knowledge surrounding possible remnants associated with historical supernovae older than about a thousand years are presented.

Supernovas in 1006, 1054, 1181, 1572 and 1604 are all discussed for completeness, although these supernovae have been extensively researched and there is little reason to doubt previous work. The historical supernovae of 185, 386, 393 and 837 are all discussed in more detail. In the opinion of the author, supernova of 185 is linked with the remnant 315.3-2.3 in the light of recent research. The supernova of 386 is linked with G11.2-0.3 and a possible record linking G11.2-0.3 with a supernova in 45BC is dismissed. An association of a remnant supernova of 393 remains unsatisfactorily resolved, with CTB37A and CTB37B remaining candidates, and the author has suggested the remnants G343.1-0.7 and G351.7+0.8 as alternatives given a new Σ-D relation. The age and suitability of GRO/RX J0852 for historical association is discussed, and political reasons for the lack of historical records for an apparent supernova in ~1200AD suggested. G292.0+1.8 is discussed as a candidate for a historical supernova and dismissed due to its invisibility in China. The supernova of 837AD is discussed and the link between this and the remnant IC443 remains unconfirmed due to conflicting astrophysical evidence.

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1 INTRODUCTION

The infrequency of supernovae events in both our own and other galaxies is inhibitive of the study of supernovae. Because of this infrequency, the importance of past supernovae events is paramount to the investigation of stellar evolution, and historical observations of supernovae are vital to the continuing development of theories of stellar evolution. The study of supernovae is complex due to wide ranges of age, type and evolution of supernovae in the universe. Historical studies of supernovae can assist astronomers greatly in their understanding of these cataclysmic events.

We are lucky enough to have many records of supernovae covering almost 2000 years of history. Although they are from many different sources, including records from the Far East, Arabia and Europe, the records form an almost complete history from which the positions and evolution of supernovae remnants can be determined, enabling astronomers to postulate and refine theories of supernovae type, structure and dynamics. Of less interest to astronomers, the records can also shed light on the ancient beliefs and politics surrounding astronomy and astronomical events.

This paper will aim to verify the work of previous astronomers and historians. Traditionally, historical astronomers have linked guest star records to known supernovae remnants, and these links will be examined where advancements in knowledge require reappraisal. Additionally, the thesis discusses those remnants that have previously been discussed as possible/probable SNRs associated with possible/probable historical supernovae, not obviously defined from the properties of the remnant, independently of historical records.

1.1 The Importance of Chinese and Other Ancient Astronomical Records

Due to the historically short time span that accurate methods of observation have been used in astronomy, historical records are of vital importance in areas of astronomy where long-term trends cannot be established by contemporaneous short-term observations by astronomers. This problem is mirrored in many areas of science, from physical geographers mapping the seemingly harmless ocean temperatures to the more threatening problem of geophysicists forecasting seismic and volcanic activity.

Since the patterns and cycles that occur in these phenomena are such long-term, and much longer than a human lifetime, short observations will not provide an accurate or reflective account of the processes concerned and will not aid theorists. In a similar vein to a geologist using records of volcanic activity from the ancient world, astronomers can use records of supernova explosions to better understand the frequency of supernovae (SNe) and the subsequent development of their remnants (SNRs).

The employment of historical astronomers in deducing such patterns as sunspot behaviour, the precession of the Earth's axis and the topic of this paper, supernovae, is becoming more and more common as astronomers realise the importance of using ancient records to fill gaps in their knowledge. Past successes in the use of astronomical records include the use of eclipse measurements made over many centuries to examine fluctuations in the rate of rotation of the Earth.

Ancient civilisations placed great importance in astronomy due to their superstitions and their astrological-type beliefs, and although we largely ridicule astrology and similar beliefs nowadays, the heavens played an important part in ancient life, whether it be in spirituality or in more practical applications such as navigation and agriculture.

It must be remembered that centuries ago, the night sky was far clearer than it is today. In modern towns and cities a few hundred stars can be seen on a clear night, but in ancient times, many thousand would have been seen and dominated the night sky. The Milky Way would have been the major body visible in the sky, and such was its brightness and the number of stars visible, that the South American civilisations formed their constellations from the patches of dark sky in the Milky Way, produced by clouds of gas and interstellar absorption, rather than from patterns of stars as the Greeks did. Such clear skies can still be seen around the world, and the difference in clarity between those and the skies we are used to in Britain are striking.

Such was the importance that these ancient peoples placed in the stars that even minor variations, such as comets and supernovae, were recorded and often taken as omens. Even over hundreds of years, the night sky would have been largely static (aside from the seasonal movements due to the orbit of the Earth) and any change in the night sky would be recognised by ancient astronomers – a supernova event being one of the more dramatic stellar phenomena visible on Earth. When it is considered that a supernova was often the brightest object in the sky, sometimes outshining the Moon and visible in the daytime, such an event would be taken very seriously by ancient astronomers and could certainly influence political decisions at the time.

2 A BRIEF CHINESE HISTORY AND ASTRONOMY IN ANCIENT CHINA

2.1 A Brief Chinese History

2.1.1 Prehistoric, Xia and Shang-era China (2200 – 1040 BC)

The recorded history of China covers some 3,600 years, through both manuscripts and artefacts. As have many cultures, China progressed through the primitive stages of society, and then through slave and feudal society. Little is known about prehistoric times in China (before 21st century BC), and ancient Chinese history is generally accepted to begin with the Xia dynasty, although until recently many historians dismissed this dynasty as myth, with almost no material remaining from these times. Indications are that the Xia descended from a Neolithic culture based around the Yellow River valley, and although no writing systems exists from this period, their system almost certainly influenced strongly the Shang oracle bone (or 'dragon bone') method of writing.

The Shang (1750 – 1040 BC) were perhaps the most advanced bronze-working people at the time, and also the most bloodthirsty. Considerable advancements in science, medicine and transportation were made during this period The Shang also provide us with the earliest Chinese ideographic writing system, with characters commonly scratched onto bones or shell for oracular purposes. The Shang considered the elements as the outpourings of a mystical power and on the occurrence of phenomena such as comets, thunder or flooding it was necessary to predict the future based on these events. Holes were drilled into tortoise shell or the shoulder blades of animals, usually from pig or bull, and then held over an open fire. The resulting cracks in the bone or shell would then be interpreted by the diviner and the outcome and dates recorded onto the bone or shell. These would then be buried to avoid sacrilege and most oracle bones have been found by archaeological excavations.

Large numbers of these oracle bones were discovered near to a main Shang capital, Yin, and also at Angyang in Henan province, and with some 100,000 bones unearthed this indicates the extent to which the Shang practised divination.

The first record of the appearance of a new star is written on an oracle bone, although there is some contention surrounding this and whether the record refers to an actual observation or a question to ancestors about offerings to the 'Great Star' and the 'Fire Star' (Antares). It was amongst oracle bone inscriptions that the term Ta-shih, or 'Grand Historian', is first encountered (see later).

2.1.2 Western and Eastern Zhou and the Warring States Period (1100 – 221 BC)

The Zhou (1100 – 771 BC) are largely considered to be more 'Chinese' than the Shang dynasty, and although the Zhou were not as advanced metalworkers as the Shang, the quality of bronze work was far superior to anything in the Western world. The Zhou also lacked the need for ceremonial human sacrifice that the Shang had. Conquering the Shang as the Shang had conquered the Xia dynasty, the Zhou ruled the most powerful principality in feudal China, bringing stability to the 'Middle Kingdom' for hundreds of years until their capital was sacked in 771 BC by invaders from the West. Ideographic script was also more widely used, with historical events recorded both on oracle bones as well as social epigraphs and stories etched onto bronze tools and utensils, and it was during the Zhou dynasty that the Emperor Wen built a large observatory for astronomical observations and calendar compilation.

Corresponding with a decline in power and influence, the Zhou moved east after the sacking of the capital, giving rise to the Eastern Zhou period. Named after the Spring and Autumn annals, the Spring and Autumn period saw a proliferation of new ideas and philosophies, and it was during this period that Confucianism, Daoism and Legalism were born. Whilst Daoism and Confucianism were largely peaceful in concept, Legalism ushered in principles that are echoed throughout Chinese history, most notably the Machiavellian way in which a nation can be controlled, ruling through extreme fear. Since the Emperor was the Son of the Heavens, there could be no legal dissent or question to his authority, and any such dissent was punished through executions, maltreatment of opponents and burning of books. It was through these principles that large amounts of both historical and astronomical records were destroyed at the change of dynasties.

The Warring States period (403 – 221 BC) saw an increase in the military strength of the individual feudal states. Whilst battles were common in the Spring and Autumn period where armies were small and battles short, the Warring States period saw large armies (500,000 strong armies were not uncommon) fighting long wars. It was during this period that Shih Shen compiled the earliest known star catalogue, containing around 800 stars (350 BC).

2.1.3 The Qin Dynasty (221 – 206 BC)

In 221BC, Qin Shih-huang united the warring states and became the first Emperor of China, so-called since the rulers of the individual states referred to themselves and kings. A committed Legalist, Qin, whose kingdom was rich in iron and hence whose army was equipped with the best weaponry, immediately burnt the books of his rivals and executed those he considered to be rivals, dissidents or just useless. Qin Shih-huang ruled the now united China ruthlessly, and despite his many achievements, such as building the original Great Wall, his method of totalitarian rule was unpopular and a series of rebellions caused the fall of the Qin dynasty soon after his death. Incidentally, his death saw the manufacture of the Terracotta Army for his mausoleum. In a repeat of history, the Qin capital was razed and the Former (or Earlier) Han dynasty had begun.

2.1.4 The Han Dynasty (206BC – AD 220)

The Han dynasty formed the basis of Chinese society which successive dynasties would utilise through the writings of Szuma Chien (145 – 86BC), and written Chinese history begins with the Han, through both the extraordinarily detailed records kept by the Han and also through the fact that they destroyed much of the legacy left by the previous Qin dynasty. Their capital was based in the western city of Chang'an (the modern day city of Xi'an in Shaanxi province), giving rise to the Former or Eastern Han moniker for this sub-dynasty. A number of child emperors held throne during the last years of the Western Han, and with the resulting regencies corruption and discontent was rife. The child emperor Cheng was deposed and the Xin Dynasty founded and remained in power briefly (AD 8-25). In AD 24, the Han dynasty was re-established by Liuxiu, a member of the imperial Han family, and relocated to the eastern city of Luoyang

The Chinese bureaucratic system was roughly based on the Confucian Classics, which provided a basis for proper and moral behaviour, and enabled the ruling classes to administer China, now the largest country in the world with some 60 million people, with a large degree of efficiency.

Integrating disparate cultures into one nation, this period saw the establishment of Han as the dominant ethnic group in China through their more advanced culture, a situation that exists to the present day.

It was during the Eastern Han dynasty that advancements in astronomical observations took place. The prominent scientist Zhangheng devised the Armillary Sphere to observe the heavens and predict earthquakes in conjunction with his work in the field of seismology (which also led him to postulate that the Earth was spherical not flat), and Cailun improved the manufacture of paper utilising plant fibres in AD 105.

The Western (Later) Han dynasty also saw notable cultural advancements, with the historian Sima Qian compiling his Records of the Historian, the first record of history from the Huangdi to the contemporaneous Emperor Wu, and the foundation of a state library to house the now increasing number of books.

It was not until an uncontrollable population shift from the Yellow River to the Yangtze in the south, and the incessant raiding from barbarians in the north, that the Han dynasty fell in AD 220, and 350 years of chaos descended on China.

2.1.5 The Three Kingdoms (AD 220 – 265) and the Dynasties of the North and South (317 – 589)

Politically, the period of the Three Kingdoms is not of any real importance to Chinese history, the period largely consisting of numerous wars between the Three Kingdoms. The ethnic Han people continued their move south and the barbarian raiders in the north began to be integrated into Chinese society. Towards the end of these periods, the notion that the reunification of China under a single emperor was reinforced and China was reunified under the Sui dynasty. A notable scientific advancement included the accurate estimate of pi by Zu Chongzhi (429-500), many centuries before the same discovery in the west.

2.1.6 The Sui, Tang and Song Dynasties

The Sui dynasty (518 – 619) was not entirely Han Chinese, and had a northern base, accounting for the barbarian influences. The Sui dynasty accomplished no more than reunifying China, unlike the subsequent Tang dynasty (619 – 907), which is regarded to be one of the greatest dynasties in Chinese history. The Tang continued the work of the Han dynasty regarding recording historical and astronomical events, and extended Chinese territories and trade links. Eventually, civil war wracked the country and after 150 years of disintegration, the Tang dynasty was overthrown.

Possibly the most important development during the Sui and Tang period as regards the historian was the development of movable wooden type, which greatly increased the numbers of records produced and almost certainly ensured the survival of many important documents. Other scientific advancements in medicine and science occurred during this period. Two in particular were the earliest recorded measurement of the Earth's meridian by the astronomer Yixing, through surveys in Henan designed to determine the length of the sun's shadow and the position of the North Pole, and a thousand years before Edmund Halley was credited with the discovery (1718), the Buddhist monk Zhang Sui (683-727) first described proper stellar motion.

Fifty years after the end of the Tang reign, an imperial army re-established the unified China and began the Song dynasty (960 – 1279). This was a time of advancements in technology, agriculture and science, and the system of government used by the Song remained until centuries later.

Subsequent invasions by Mongols and Tartars influenced Chinese history, but the way of life and sociological systems remained largely unchanged throughout dynastic history. Later scientific developments included the construction of a number of large astronomical instruments (such as the Ecliptic Armillary Sphere and the 'Quadrant' constructed under the guidance of Belgian missionary Ferdinand Verbiest) and the publication of sizable numbers of astronomical documents (including the notable *Lingtai Yixiang Zhi*[1], *Lixiang Kaocheng*[2] and *Yixiang Kaocheng*[3]) during the Qing (1644-1754) dynasty.

2.2 Chinese Astronomy

Important to all ancient cultures, but most apparent in ancient China, astronomy was central to spiritual life. It is almost certain that astronomy, and indeed science in general, evolved independently from other civilisations, and in many cases Chinese science was far more advanced than elsewhere. The major factor limiting progression in Chinese astronomy in particular was the fact that many posts in the Astronomical Bureau were hereditary, causing a degree of stubbornness towards change or advancement. Astronomical techniques in China remained largely the same for centuries until Jesuit influences in the sixteenth century refined Chinese astral cartography.

The purpose of the Emperor of China was not to control his people in the normal sense, but to maintain harmony between the heavens (*tien*) and Earth, with harmony ensuring the longevity and stability of life. Indeed, the

[1] Translation – "*Catalogue of Astronomical Observatories and Instruments*"
[2] Translation – "*Complete Studies on Astronomy and Calendar Books 1 and 2*"
[3] Translation – "*Complete Studies on Astronomical Instruments Books 1 and 2*"

Emperor was literally the 'Son of Heaven' and received his authority from the heavens rather than from a supreme god or gods. This authority was called *tien ming* ("The Mandate of Heaven"). *Tien ming*, an advancement of the *shangti* ("Lord on High") belief, is perhaps the most important concept in socio-political ancient China, and provides a moral system where the Emperor is required to serve the people selflessly.

This hierarchy is captured in the ideograph for 'emperor' with the three horizontal strokes representing the heavens, man and the Earth respectively, and the vertical stroke representing the axis joining the Earth to the heavens.

王

Figure 1.1 – *The Chinese Ideograph for 'Emperor'*

Agriculture was also a major part of the Chinese economy, and by accurate observations of the night sky, seasonal changes could be accounted for, aiding the planning of sowing and reaping crops. Such was the night sky's importance both in spiritual and agricultural life; the officials concerned with astronomical affairs were highly revered in society. The *Xia xiaozheng* (The Lesser Calendar of the Xia, apparently originating from the Xia dynasty, but is probably much younger) describes how the appearance of star groups heralded the beginning of the seasons.

The ancient Chinese believed that harmony could be maintained through a series of rituals and decrees read in the Ming Tang, or the Hall of the Calendar. The Ming Tang was a square building with walls aligned to the primary directions with the roof representing the heavens and each wall corresponding to a season of the year. The decrees came from the Emperor and read in the Ming Tang in varying positions depending on the time of year -his position in the Ming Tang was related to the ‘handle’ of Ursa Minor, with astronomers tracking its position in the sky from the coniform roof of the Ming Tang. The rituals are described in the Li Han, a compendium of ancient texts and rituals compiled during the Han dynasty.

The Emperor would always face south whilst performing such ceremonies – south is both the direction of the fullest sun and the direction in which the Polaris ‘faces’. Believed to be intrinsically linked with the Emperor, Polaris was referred to as ‘Great Sovereign of the Sky’ and ‘Central Palace of the Sky’ by the Chinese.

The belief that a person could be linked to a star was not limited to just the Emperor. The stars surrounding Ursa Minor were identified with officials, courtiers and parts of the Imperial Palace. Kochab (β-Ursae Minoris), the second brightest star in the constellation of Ursa Minor, was linked to the Prime Minister and the next brightest star represented the Imperial Prince. Depending on the rank and importance of the person, the brightness of the star associated with them would vary, with the dimmer stars in the Ursa Minor region assigned to people such as the Imperial Guard. These associations were not limited to Ursa Minor – stars in Draco were linked to officials such as the Great Judges and Censors, and stars in Ursa Major linked to the tutors of the Imperial Prince and Household Officials.

2.2.1 The Astronomical Bureau and Astronomical Records

As described earlier, the heavens were intrinsically linked to events on the Earth, and from as early as the Shang dynasty, and certainly during the Zhou dynasty, a Grand Historian, or Ta-shih recorded both natural phenomena and human events. The post of Grand Historian is believed to have existed from the Shang dynasty since references to Ta-shih have been found amongst oracle bone records. During the Han dynasty, the post and duties of the Grand Historian were refined, and the Office of Sacrificial Worship, or *Tai-chang*, established, separating the duties of historical and astronomical observation due to the increasing importance and complexity of politics at the time. The Office of Sacrificial Worship is usually referred to as the Astronomical Bureau, and this existed until recent times. Ho Peng Yoke made a detailed study[4] of the Astronomical Bureau in Ming China, and related the tasks of the Bureau:

> "With the help of the Bureau staff they (i.e. the Director and Deputy Director of the Bureau) observed or took measurements on the Sun, the Moon, the stars and asterisms, winds and clouds, and the colour of vapours, and submitted confidential reports to the Emperors whenever there were abnormalities."

The staff of the Astronomical Bureau would note every possible observation and the Father Lecomte, a member of the French Jesuit mission that visited China in 1685 provided a useful account[5] of the workings of the Qing Astronomical Bureau. He recounted that five 'mathematicians' spent every night on a tower watching the skies (four facing towards each of the primary directions and one looking towards the zenith) and they noted "the Winds, the Rain, the Air, of unusual Phenomenas, such are Eclipses, the Conjunction or Opposition of Planets, Fires, Meteors, and all that may be useful." These records were then taken to the 'Surveyor of the Mathematicks' (as Lecomte described him) for registration.

As previously stated, the oracle bones contain little of interest as regards supernovae. The only real reference to any astronomical events are related to eclipses, and the few references to 'new stars' are largely useless given

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[4] Ho Peng Yoke, *J.Asian History*, 3, 135 (1969)

[5] Translation contained in *Science and Civilisation in China, vol.3*, J. Needham. (Cambridge Univ. Press, 1959)

the lack of any dates or durations, and the possibility that such 'new stars' are supernovae is highly debatable.

The first reliable records are those contained in the Spring and Autumn Annals (Chunqiu) dating from 722 to 421BC. The annals contain references to eclipses, and also contain the first known record of a comet ('bushy' star or *xingbo*); the comet sighted in 613 BC. The major problem when looking at phenomena from this period is the lack of official records, the vast majority having been burnt in 213 BC by the Legalist Qin Shih-huang. Again, as previously stated, the Han dynasty saw the beginning of reliable official records and astronomical events were recorded in the dynastic histories (*zhengshi*) usually compiled from existing records made during the preceding dynasty. These dynastic histories were often written onto bamboo or silk with paper widely used from AD 100, and the advent of block printing resulted in the loss of the original documents.

The dynastic histories were considered to be the official history of the dynasty, and although they can be considered largely reliable, political events were often censored or paraphrased at the discretion of the official historian. Many astronomical records were summarised for conciseness, losing some of the more useful detail of the initial observations. The histories were divided into four, the 'Basic Annals' (*benji*), 'Treatises' (*zhi*), 'Chronological Tables' (*biao*) and 'Biographies' (*liezhuan*). The Tianwen-zhi ('Astronomical Treatise') is contained within the main treatises of the history and contains the (summarised) records and interpretations of the dynasty. Phenomena such as eclipses and comets were also mentioned in other sections where they were appropriate. These dynastic histories are only really needed until the time of the Song, when more detailed records are available elsewhere, such as in the *Wenxian Tongkao*[6] and *Ming Shilu*[7], two notable works.

[6] Translated as *'Comprehensive History of Civilisation'*

Dynasty/History[8]	**Period**	**Chapter**
Hanshu	206BC – AD 9	26
Hou Hanshu	AD 23 – 220	21
Jinshu	220 – 420	13
Songshu	220 – 479	23
Weishu	377 – 533	105
Suishu	502 – 618	21
Jiu Tangshu	618 – 907	36
Xin Tangshu	618 – 907	32
Jiu Wudaishi	907 – 960	34
Xin Wudaishi	907 – 960	59
Songshi	960 – 1279	56
Jinshi	1127 – 1234	20
Mingshi	1368 - 1644	27

Table 2.1 *Chinese Astronomical Treatises Containing Guest Star Records*[9]

2.2.2 *The Chinese Calendar and Timing*

The basis of the ancient Chinese society and economy was agriculture, so the adoption of an accurate calendar from which seasons could be determined was crucial to the Chinese, and such a calendar was used as early as during the reign of the Shang. The calendar began numbering from the beginning of the reign of a dynasty (or sub-reign upon accession within a dynasty, a scheme first introduced during the Han dynasty by Emperor Wen). The date of the New Year was determined by the winter solstice that must fall within the 11th lunar month. The duration of a year was usually 11 or 12 months but after two or three years a month was added to keep the seasons in step with the calendar in a similar way to a leap year.

[7] Translated as '*Veritable Records of the Ming Dynasty*'
[8] Two histories are recorded for the Tang dynasty, *jiu* (old) and *xin* (new). There are two terms used in the names of the histories, *shu* ('book') and *shi* ('history').
[9] Reproduced from *Historical Supernovae and their Remnants*, F.R.Stephenson & D.A. Green (2002) Clarendon Press

Furthermore, the months began with a new moon and the year was divided into four groups of three months, each group becoming a season.

Days were divided into twelve *shi*, or double hours, or into five *geng*, or night watches. The division into shi was fairly straightforward, with each shi corresponding to two hours, the only difference being that the first shi (*zi*) was centred on midnight and so the day (began or ended) at 11pm.

A different method of time measurement was to use *geng*. The night was divided into five geng (with the length of a geng dependent on the time of year) with a short period of twilight either side of night time, dusk (*hun*) and dawn (*dan* or *ming*). The day officially began[10] at sunrise (*richu*) and ended at sunset (*riru*). Although by the time of the Song dynasty water clocks, the preferred method of timing, were becoming quite accurate, few records give accurate timings.[11]

2.2.3 *Astrography, Asterisms and Lunar Mansions*

The earliest star maps and catalogues date from the Han dynasty – it is likely that the skies were mapped earlier this, but these have been lost during changes of reign. The earliest original whole map that still survives is from around AD 700 and shows most asterisms. By 300 BC the sky had been divided into some 300 asterisms, and although no maps exist of these, inscriptions indicate the degree to which the sky had been mapped. The oracle bones of the Shang period describe the planet Jupiter and the constellation *Dou*, most likely identical to the Plough, and the bones are the earliest record of the Chinese grouping stars into constellations or asterisms.

[10] Although the date began at midnight, the date was not changed until dawn for astronomical records, presumably to avoid confusion.
[11] The descriptions of the timing system are adapted from *Historical Supernovae and their Remnants*, F.R. Stephenson & D.A. Green, Clarendon Press (2002)

The asterisms were constructed from the visible stars in China (to declination –55°) and could be made from groups of stars ranging from 1 to 30 in number and are not related to the Greek constellations with the exception of Ursa Major or *beidou*. There were three major star groups, two being known as 'palaces' (*Ziwei gong* and *Taiwei gong*) and the third known as the 'Celestial Market' or *Tianshi*. Most astronomical records are referenced with respect to one or several of the asterisms.

In a similar vein to the Greek zodiac, 28 asterisms (*xiu*) denoted 'lunar lodges' or 'lunar mansions' and are found placed around the celestial equator. The lodge was named after the asterism it was associated with and its western boundary marked by one of the stars in the associated asterism. Star maps usually show the celestial sphere divided into the 28 *xiu*, although the *xiu* were not of equal size. Around 300 AD, the widths of the *xiu* were altered when the Chinese became aware of the precession of the Earth. The lodges were utilised in astrology and their importance was similar to that of the signs of the zodiac although Chinese astronomy was equatorially based unlike Greek astronomy.

Number	Name	Tranlsation
1	*Jue*	Horn
2	*Kang*	Neck
3	*Di*	Base
4	*Fang*	Chamber
5	*Xin*	Heart
6	*Wei*	Tail
7	*Ji*	Basket
8	*Nandou*	Southern Dipper
9	*Niu*	Ox
10	*Xunu*	Maid
11	*Xu*	Emptiness
12	*Wei*	Rooftop
13	*Yingshi*	Encampment
14	*Dongbi*	Eastern Wall
15	*Kui*	Stride
16	*Lou*	Harvester
17	*Wei*	Stomach
18	*Mao*	Mane
19	*Bi*	Net
20	*Zuixi*	Turtle Beak
21	*Shen*	Triad
22	*Dongjing*	Eastern Well
23	*Yugui*	Ghost Vehicle
24	*Liu*	Willow
25	*Qixing*	Seven Stars
26	*Zhang*	Extended Net
27	*Yi*	Wings
28	*Zhen*	Axletree

Table 2.2 – *Chinese Lunar Lodges*

A set of Chinese star maps, showing the asterisms and Lunar Lodges can be found in Appendix IV. Also plotted on the maps are the supernova remnants found in David Green's supernova catalogue.

3 STELLAR EVOLUTION AND SUPERNOVAE

The material in this section is abridged from M. Zeilik et al., *Introductory Astronomy & Astrophysics* (1992, HBJ), E. Böhm-Vitense, *Introduction to Stellar Astrophysics* (1992, Cambridge) and I.S. Shklovsky, *Supernovae* (1968, Wiley) and is included for completeness.

3.1 Introduction

Normal stars radiate because of high-energy collisions that fuse atomic nuclei inside the star. The fusing of light nuclei into progressively heavier nuclei releases energy and hence the stars radiate. This occurs since the collision between the nuclei causes the nuclei to lose mass. This mass does not disappear, but is converted into energy. This is a much-simplified explanation, and this chapter will look at this process in more detail, and how this affects the evolution of a star until its demise in the form of a supernova.

A star begins its life as a massive cloud of gas and dust that exists between stars, known as the interstellar medium (ISM). Throughout a star's lifetime, much of this material will be returned to the ISM through stellar winds and explosive events. If there is sufficient gas, the cloud will contract gravitationally, heating up as it collapses and provided there is enough mass, the star will contract sufficiently that the temperature will be high enough for nuclear fusion to begin, otherwise the star will become a *brown dwarf*, or failed star. Interestingly, supernova remnants may be responsible for star formation, as the shockwaves propagated by the explosion could cause the collapse of gas clouds.

To prevent the star from contracting further, the energy generated in the star has to balance the energy loss at the surface of the star and the star is said to be in *hydrostatic equilibrium* and the diameter is fixed by the mass of material in the star. The energy release from gravitational contraction is a factor of 100 too small to keep a star shining, although it may initially power young stars. The only mechanism that can supply enough energy is nuclear fusion.

3.2 Energy Sources and Reaction Chains

Energy of around 1 percent of the rest mass of the proton can be gained from fusing hydrogen nuclei into heavier nuclei. The mass difference between the rest masses of the colliding nuclei and the resultant heavier nuclei releases energy according to Einstein's relation

$$E = \Delta mc^2 \qquad (3.1)$$

However, this does not completely explain the probability of nuclear fusion within the star. A nuclear reaction between two protons is unlikely since there is no stable helium nucleus with two protons and no neutrons. The only likely reaction is for two protons to fuse to form a deuteron, and for this to happen, one of the protons must become a neutron by positron emission, and this event is rare, although it can happen for relatively low temperatures, in the order of several million degrees.

Once two protons have combined to form a deuteron, D^2, subsequent reactions occur quickly. At low temperatures, the PPI chain of reactions occur

$$\begin{aligned} H^1 + H^1 &\rightarrow D^2 + e^+ + \nu \\ D^2 + H^1 &\rightarrow He^3 + \gamma \\ He^3 + He^3 &\rightarrow He^4 + H^1 + H^1 \end{aligned} \qquad (3.2)$$

The reaction chain can end in the following way, known as the PPII chain

$$\begin{aligned} He^3 + He^4 &\rightarrow Be^7 + \gamma \\ Be^7 + e^- &\rightarrow Li^7 + \nu \\ Li^7 + H^1 &\rightarrow He^4 + He^4 \end{aligned} \qquad (3.3)$$

or by the PPIII chain

$$\begin{aligned} Be^7 + H^1 &\rightarrow B^8 + \gamma \\ B^8 &\rightarrow Be^8 + e^+ + \nu \\ Be^8 &\rightarrow 2He^4 \end{aligned} \qquad (3.4)$$

For higher temperatures, reactions with heavier nuclei can become important. In the CNO cycle, the main cycle comprises

$$\begin{aligned} C^{12} + H^1 &\rightarrow N^{13} + \gamma \\ N^{13} &\rightarrow C^{13} + e^+ + \nu \\ C^{13} + H^1 &\rightarrow N^{14} + \gamma \\ N^{14} + H^1 &\rightarrow O^{15} + \gamma \\ O^{15} &\rightarrow N^{15} + e^+ + \nu \\ N^{15} + H^1 &\rightarrow C^{12} + He^4 \end{aligned} \qquad (3.5)$$

Different cycle endings are possible, as with the PP chain.

$$\begin{aligned} N^{15} + H^1 &\rightarrow O^{16} + \gamma \\ O^{16} + H^1 &\rightarrow F^{17} + \gamma \\ F^{17} &\rightarrow O^{17} + e^+ + \nu \\ O^{17} + H^1 &\rightarrow N^{14} + He^4 \end{aligned} \qquad (3.6)$$

For higher temperatures still, a reaction chain

$$\begin{aligned} Be^{8} + He^{4} &\rightarrow C^{12} + 2\gamma + 7.6\,\mathrm{MeV} \\ He^{4} + He^{4} &\leftrightarrow Be^{8} - 95\,\mathrm{keV} \\ Be^{8} + He^{4} &\rightarrow C^{12} + 2\gamma + 7.4\,\mathrm{MeV} \end{aligned} \qquad (3.7)$$

can occur at around 10^{8} K. This is known as the triple-alpha process since it requires three alpha particles (He^{4}) to form one C^{12} nucleus. The triple-alpha reaction produces carbon and conditions appropriate for oxygen to be produced but it is possible that heavier elements are not produced. For massive stars, reactions and mechanisms can be identified whereby all elements up to uranium can be formed.

3.3 Evolution of Active Stars

Once the star has collapsed and begun nuclear fusion via the PP chain, or hydrogen burning, the star begins its life proper on the main sequence. Most stars are on the main sequence, purely because the main sequence lifetime is the longest stage of a star's life.

As the star's life progresses, gradually the hydrogen in its centre will become depleted, since fusion is most efficient in the centre, and eventually run out, and the star can no longer generate energy via the PP chain, and the CNO cycle becomes more important. However, the core temperature will have increased sufficiently that hydrogen burning can continue in a thick shell surrounding a small and predominantly helium core. As the hydrogen is burnt in the shell and the fusion region expands outwards, the predominantly helium core increases in mass, and eventually the helium core is too massive to support the material above it. The maximum fraction of a star's mass in an isothermal core that can support the material above it is known as the *Schönberg-Chandrasekhar limit.* At this point, the core collapses, compressed by self-gravitation, and the temperature and density of the hydrogen-burning shell increases together with an increase in the rate of energy generation. This causes the envelope of the star to expand, decreasing the surface temperature. The star enters the sub-giant phase of its life.

Helium-burning starts in the core and the stellar surface becomes hotter and brighter and by this time the star may be a supergiant. A light star (< 1 $M_\odot$) may throw off its envelope at this point as it is not hot enough to continue burning helium and will contract to form a helium-rich white dwarf or even cool to form a brown dwarf. Stars with a mass around that of the sun will continue to burn helium in the core and eventually form a white dwarf. The mass of these stars is not enough to start carbon burning and a planetary nebula will probably be formed from the now ejected helium-rich envelope of the star.

For stars with an original mass greater than around 8 solar masses, a neutron star may be formed. The degenerate gas pressure of the star cannot resist gravitational contraction and a dense, degenerate neutron star is formed. If the inert core of the star is greater than 1.4 $M_{\odot}$, the star will continue to supernova which may result in a neutron star or black hole.

3.4 Supernovae

The fate of stars greater than around 8 solar masses is different to lighter stars. The helium-burning shell continues to add material to the carbon-oxygen core, and as the core contracts, carbon burning is possible, generating heavier by-products. The successive nuclear reactions, assuming each burns to equilibrium, cause an onion-like structure, culminating with a dense iron core, and fusion shells, each burning a progressively lighter element, sandwiched between convection zones. The temperature is now great enough for heavy nuclei to be broken apart by photons via photodisintegration. The most important processes are

$$
\begin{aligned}
{}^{56}_{26}\mathrm{Fe} + \gamma &\rightarrow 13\,{}^{4}_{2}\mathrm{He} + 4n \\
{}^{4}_{2}\mathrm{He} + \gamma &\rightarrow 2p^{+} + 2n
\end{aligned}
\qquad (3.8)
$$

The process by which photodisintegration occurs is highly endothermic, and this removes energy from the core, which is required to support the core against collapse. Under these now extreme temperatures and pressures, the electrons that had supported the star through degeneracy are captured by heavy nuclei and protons.

$$p^{+} + e^{-} \rightarrow n + \nu_e \quad (3.9)$$

The core's support is now removed by photodisintegration and electron capture, and it collapses rapidly, with the inner core detaching itself from the outer core when the collapse speed exceeds the local speed of sound causing inhomologous collapse. The outer layers of the star, including the fusion shells, are also detached from the core and are left behind. The collapse of the inner core continues until the density becomes so great that due to the Pauli exclusion principle, the strong force switches to become repulsive. The inner core rebounds at a density of about 8 x 10^{14} g cm^{-3}, and sends out pressure shock waves.

As the shock wave hits the detached outer core, the still high temperatures cause further photodisintegration, causing the wave to lose energy. If the outer core is massive enough to stall the wave, material accretes onto the wave, and is known as an accretion shock. Below the stalled shockwave, and neutrinosphere develops from the photodisintegration and electron capture process, and the energy from this heats up the shockwave sufficiently for it to continue through the outer core. This is known as a *delayed explosion mechanism.*

If the shockwave is not massive enough to stall the wave, the shockwave progresses through the core and collides with the outer envelope. This is known as *prompt hydrodynamic explosion.* In either case, the shockwave forces the envelope outwards into the ISM, and when the envelope becomes optically thin at a radius of 10^{12}m, a peak luminosity of 10^9 $L_\odot$ results, which is comparable to the brightness of a small galaxy.

If the initial stellar mass is less than approximately 25 solar masses, the inner core will stabilise and form a neutron star. This is supported by neutron degeneracy pressure and if the initial mass was larger than 25 $M_\odot$, the degeneracy cannot balance the self-gravitational pull and the core collapses, forming a black hole.

Note that a supernova is distinct from a nova; the latter is a sudden brightening of a star due to the onset of fusion in matter accreted onto the surface of a white dwarf or neutron star.

3.5 Type II Supernovae

Type II supernova are thought to be caused by the previously described mechanism. Type II supernovae are observed to have a sudden increase in luminosity, peaking at an absolute magnitude of around –18 and then decrease in luminosity gradually, by around 8 magnitudes each year. Their spectra show both strong hydrogen and heavier elemental spectral lines.

The light curves of Type II supernova can be sub-classified into two. They can be seen to have a well-defined plateau at maximum brightness (Type II-

P) or show no plateau and a linear fall-off (Type II-L). For Type II-P supernova, the plateau is apparent for 30-80 days. The source of this plateau can be attributed to the radioactive decay of isotopes, particularly ${}^{56}_{28}\mathrm{Ni}$, formed by the progression of the shockwave front through the star. Other isotopes with relatively short half-lives are also prominent, such as ${}^{57}_{27}\mathrm{Co}$, ${}^{22}_{11}\mathrm{Na}$, and ${}^{44}_{22}\mathrm{Ti}$. The decay of these isotopes, provided they are present in sufficient amounts, contribute to maintaining the luminosity of the supernova, since the energy released by the decay is radiated away by the supernova's photosphere. ${}^{56}_{28}\mathrm{Ni}$ beta-decays into ${}^{56}_{27}\mathrm{Co}$ via the following reaction

$$ {}^{56}_{28}\mathrm{Ni} \rightarrow {}^{56}_{27}\mathrm{Co} + e^{+} + \nu_e + \lambda \qquad (3.10) $$

The product of this is also radioactive, and decays as follows

$$ {}^{56}_{27}\mathrm{Co} \rightarrow {}^{56}_{26}\mathrm{Fe} + e^{+} + \nu_e + \gamma \qquad (3.11) $$

Since the luminosity of the supernova will decrease over time, it is possible to detect the contribution to the light curve by each isotope. The rate of decay is proportional to the number of atoms,

$$ \frac{dN}{dt} = -\lambda N \qquad (3.12) $$

and by integrating this,

$$ N(t) = N_0 e^{-\lambda t} \qquad (3.13) $$

where N_0 is the initial number of radioactive atoms, and

$$ \lambda = \frac{\ln 2}{\tau_{1/2}} \qquad (3.14) $$

Since *dN/dt* is proportional to the rate of production of decay energy, the slope of the light curve is given by

$$\frac{d\log_{10} L}{dt} = -0.434\lambda \qquad (3.15)$$

By measuring the slope of the light curve, the presence of quantities of a radioactive isotope can be determined. The composition and contribution of radioactive isotopes to the supernova SN 1987A, first observed on February 24th, 1987 were determined in this way.

This supernova was seen using a 10-inch astrograph at the Las Campanas Observatory, Chile in the Large Magellanic Cloud. This was the first supernova seen in close proximity (~50 kpc) to Earth, and was immediately seen to be unusual. It exhibited a slow increase to maximum brightness and only peaked at a magnitude of –15.5 compared to the usual –18. This was explained due to the fact that the star that exploded was a blue supergiant star, which was much smaller than the expected red supergiant. Since the star was denser, the shockwave was unable to immediately break out from the envelope of the star and diffuse outwards as light. The composition of the supernova was such that the decay of various radioactive isotopes mirrored the decrease in luminosity of the supernova and the light curve could be accurately analysed using knowledge of the decay mechanisms.

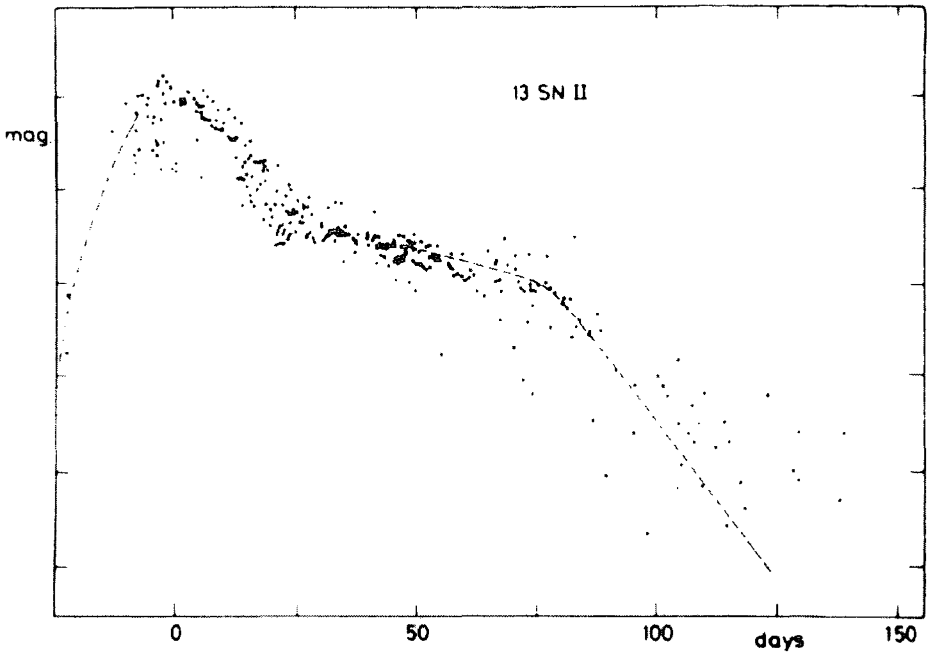

Figure 3.1 – *Composite Light Curve of a Type II Supernova from 13 Type II SN Observations*[12]

3.6 Type I Supernova

The classification for supernovae is based on the characteristic of the supernovae at maximum brightness. As opposed to Type II supernovae that do, *Type I* supernovae do not exhibit hydrogen lines in their spectra. Type I supernovae can be further classified into three groups. Type Ia supernova show a strong Si II line at 6510 Å. Type Ib supernova exhibit strong helium lines and Type Ic do not exhibit helium lines. The differences in the composition of the spectra for Type I supernova reflect the fact that different mechanisms are responsible for their presence. Type Ia supernovae are found in all galaxies, whereas Type Ib and Ic have only been recorded in spiral galaxies, suggesting that the explosion of short-lived but massive stars results in Ib or Ic supernovae. Massive Wolf-Rayet stars may also be responsible for some Type Ib and Ic supernovae.

[12] Reproduced from Barbon et al. (1975)

The light curves of Type I supernovae are all similar and there is no sub-classification, as opposed to the differing light curves for Type II-L and Type II-P supernovae. The rate of decline of brightness is the same for all Type I supernovae, dropping around 0.065 magnitudes per day for around 20 days. After approximately 50 days, the rate of dimming slows and remains constant, although Type Ia supernovae decline 1.5 times faster than the other types.

For Type Ia supernovae, the explosion is best modelled by the explosion of a white dwarf accreting material in a close-binary system. When the mass of the white dwarf is 1.30 $M_\odot$, carbon-burning starts at the centre of the star. In a similar mechanism to that of a helium flash, the increase in temperature due to carbon burning does not result in an expansion of the core, meaning that the burning region gradually expands towards the surface of the dwarf. About 50% of the mass of the white dwarf is converted to iron before the removal of the degeneracy of the dwarf. The star expands as a result, cooling the interior sufficiently for fusion to stop. The energy released by this process disrupts the star and a Type Ia supernova is resultant. The outer layers of the star are blown off at high speeds, whilst the innards are ejected at lower speeds. This accounts for the presence of carbon in the spectral lines of Type Ia supernovae, since it is not completely burnt.

Although this model is reasonable in the account for Type Ib and Ic supernovae, their association with spiral galaxies and star formation mean that a model for Ib and Ic supernovae must accommodate high mass and short-lived stars. A contemporary model is that the supernovae are resultant from stars of around 20 $M_\odot$ and as the star evolves, stellar winds or a close binary strips the star of its hydrogen envelope leaving a core with a surface layer of helium with heavier elements found deeper towards the iron core. This accounts for the lack of hydrogen lines in their spectra. The explosion mechanism is similar to Type II supernovae with a collapse and rebound of the iron core. It is also postulated that an explosion of a more massive star than those associated with Type II supernovae would produce less radioactive isotopes, which would account for the less bright light curves. Helium-poor stars in the case of Ic and helium-rich in the case of Ib could explain the differences in Type Ib and Ic spectra.

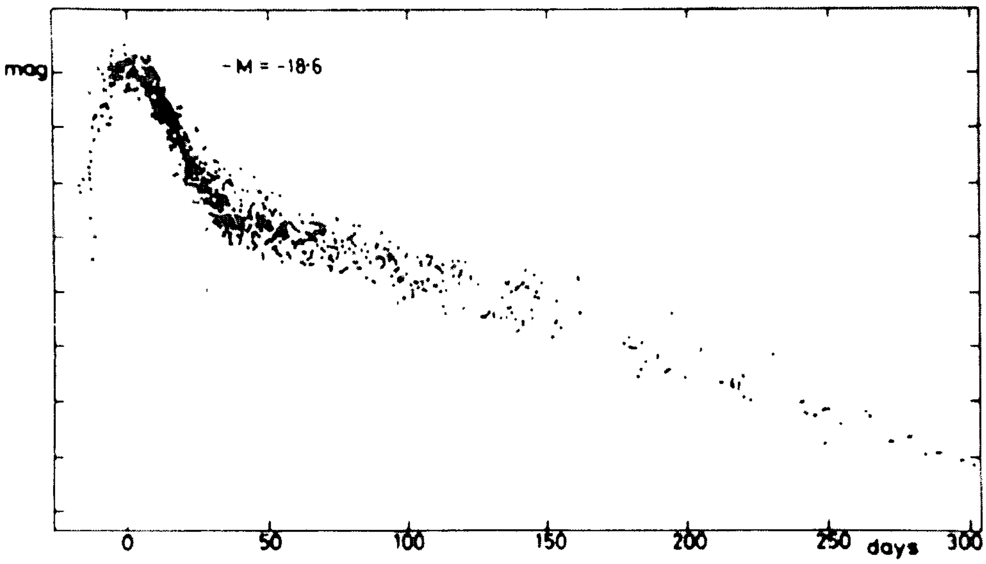

Figure 3.2 – *Composite Light Curve of a Type I Supernova from 38 Type I SN Observations*[13]

3.7 Supernova Remnants

SNRs are mainly detected at radio wavelengths, and are generally located in the galactic plane (see the maps at the end of the thesis). However, SNRs that are distant and/or faint are difficult to detect through large-scale radio observations due to their similarity to the galactic radio background or simply due to the fact they cannot be resolved.

[13] Reproduced from Barbon et al. (1974)

In contrast to the five different types of supernova, there are only three recognized classes of supernova remnant (SNR). This can initially be explained by the fact that the supernovae share similar features that determine the remnant left.

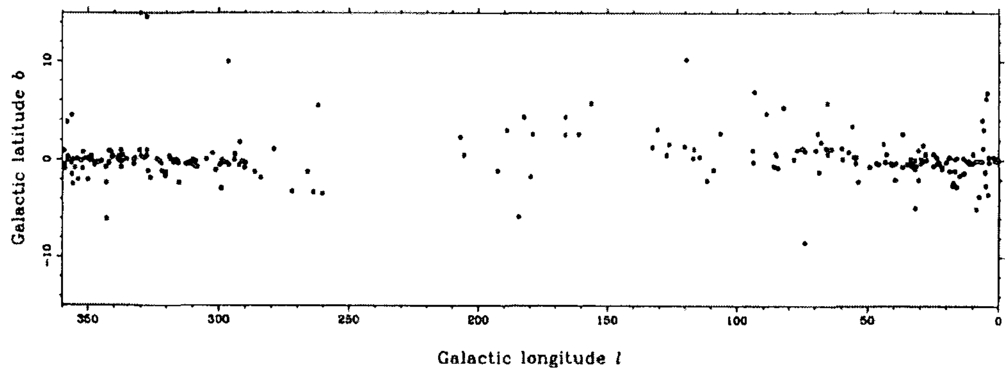

Figure 3.3 – *Location of Galactic SNRs*[14]

3.7.1 Shell Remnants

The first type of remnant is known as a *shell-type* SNR and is thought to be usually caused by the explosion of a white dwarf in a Type I supernova although there are exceptions (for example Cas A). These are characterized by large masses of gas expanding out into the ISM and are differentiated from the ISM by the emission of synchrotron radiation. They are the most easily recognised SNR due to their bright 'shell' of radio emission. An ideal shell SNR would show a spherical (seen as circular) shell of expanding ejected gas, although an old shell SNR will not have a perfectly spherical shell from prolonged expansion into the non-uniform ISM, with some SNRs exhibiting an arc rather than a complete shell.

[14] Reproduced from Green & Stephenson (2002)

The remnants of Tycho's (AD 1572), Kepler's (AD 1604) and the Cygnus Loop supernovae the most well known examples of shell remnants, although the Cygnus Loop remnant is much older than either Tycho's or Kepler's. Most remnants are shell remnants and account for 84% of catalogued SNRs.

3.7.2 Evolution of Shell Remnants

As will be the case for the evolution of any SNR, or indeed any stellar structure, factors such as the initial mass, the final structure of the dying star and the immediate surroundings will influence. More massive stars that shed material during their lifetimes, such as Wolf-Rayet stars, will also evolve slightly differently due to the presence of this material before supernova.

In the first phase of the evolution of the remnant, the SNR expands into the ISM and since the mass of the SNR is much greater than that of the ISM, the deceleration of the SNR is negligible. The radius of the SNR increases with time as $r \propto t$. This phase of the SNRs lifetime lasts in the order of a few hundred years.

The next phase of the SNR's evolution is known as the Sedov-Taylor expansion and is adiabatic in nature. The SNR expands further into the ISM and the dynamics of the expansion is considered as an explosion releasing no energy into a homogeneous material. In practice the ISM will most likely not be homogenous. Shockwaves are formed both outwards and inwards with the radius evolving as $r \propto t^{2/5}$. The Sedov-Taylor phase lasts around 1000 years.

The remnant is still expanding into the ISM but cools as it does so. A shell of material is formed. In the final phase of evolution, the remnant is cooled further and merges into the ISM.

An alternative evolution process, as is thought to be the case with the Cas A SNR, is where a massive giant star sheds its envelope and contracts to form a blue giant. The compact core radiates strongly and can collect the ejected material into a dense surrounding shell which expands rapidly. This shell of material would be expected to interact with the eventual supernova and the spectra from Cas A can be explained by this, whereby the material from the exploding star collides with the older, pre-supernova surrounding shell. Elements present in the shell suggest that much of the material is older than material expected to be present in a shell formed solely from a supernova event.

3.7.3 Plerionic Remnants

Plerionic remnants are associated with all types of supernova except Type Ia explosions. Also known as 'Filled-Centre' or 'Crab' remnants, they exhibit a 'filled' appearance with strong emission lines across their surface, and pulsars have sometimes been found at their centres. The evolution of these remnants is not well understood. The remnants are both dense and compact and suggest that the progenitor was a massive star. It is not possible to differentiate between the differing types of supernova on observations of this type of remnant alone.

The Crab Nebula is the most well recognised plerionic remnant, and is almost certainly the remnant of the AD 1054 supernova. In the case of the Crab Nebula, a pulsar has been observed at the centre of the remnant, although it must be stressed that this is not typical of all plerionic remnants.

Although Plerionic remnants are less common than the other types, comprising 4% of all recorded SNRs, it is more difficult to detect these

SNRs since they lack the easily recognisable limb-brightened shell of shell type SNRs. The radio spectra of these remnants are also easily mistaken for areas of HII. With improved observations, some shell remnants may be reclassified as plerionic SNRs as the areas within the shell are examined more carefully.

3.7.4 Composite Remnants

The third type of remnant is the *Composite* SNR with 12% of the catalogued SNRs being composite remnants. These exhibit characteristics of both shell and Plerionic remnants, for example the SNR G21.5–0.9 was classified as Plerionic in 1976, before a faint x-ray shell was found around the remnant by radio observations in 2000.

3.8 Pulsars

Supernova explosions can result in the formation of pulsars, or rapidly rotating neutron stars that emit radio beams in a similar way to a lighthouse. The beams are resultant from the powerful magnetic field of the pulsar. Pulsars are useful in that the rotation rate of the pulsar is precise, with periods between 0.1s and a few seconds, and this rate is gradually slowing down with the loss of rotational energy. This rotation rate can be used to determine other properties of the pulsar and also its distance from Earth.

The characteristic age of the pulsar is given by

$$t = \frac{p}{2\dot{p}}$$

where p is the period and $\dot{p}$ the first derivative of the period.

For a pulsar to be associated with a remnant, the ages of the remnant and the pulsar need to be in agreement, and also the distance, although the pulsar will move from the position of formation (usually at the centre of the remnant). A young remnant that also has an associated pulsar will usually have the pulsar near to the centre, and an older remnant may have its pulsar completely outside of itself.

3.9 The Σ-D Relation

The relation between the surface brightness of a remnant and its distance from Earth has traditionally been used for distance measurements. This can be used if other methods of distance determination, such as HI absorption, cannot be used. The relation is based on the fact that a large SNR will be less bright than a small SNR, and from the brightness the diameter is estimated. Using the diameter, the usual angular method of distance determination can be used. Hence,

$$\Sigma \propto \frac{L}{(\theta d)^2} \qquad \text{or} \qquad \Sigma \propto \frac{L}{D^2}$$

where Σ is the surface brightness, L is the luminosity, θ is the angular size, D is the diameter and d is the distance.

4 CANDIDATES FOR HISTORICAL SUPERNOVAE

4.1 Introduction

In this chapter, several remnants will be presented as candidates for historical supernovae. Their candidacy will be based on the likelihood that their progenitor stars exploded within the last 3000 years – there will be some uncertainty due to the difficulty in determining the exact ages of supernovae but an estimate of age will be provided. Largely, the work of determining the age of supernova remnants is the domain of radio and x-ray astronomers and much of their work will be used in presenting the candidates.

The likelihood of the candidates being historical supernovae will then be discussed using Chinese texts exclusively, although where necessary texts from other sources will be used for verification.

The remnants that are being presented as possible candidates are listed in Table 4.1.

SNR	R.A	Dec.	Date of SN	*Green*	Notes
G315.4–2.3	$14^h43^m00^s$	-62°59'	185 AD	159	RCW 86, MSH 14-63
G320.4–1.2	$15^h14^m30^s$	08°30'	185 AD	166	RCW 89, MSH 15-52
G11.2–0.3	$18^h11^m27^s$	-19°25'	386	23	
G346.6-0.2	$17^h10^m19^s$	-40°11'	393 / 396	203	
G348.5+0.1	17^h14^m	-38°32'	393 / 396	206	CTB37A
G348.5-0.0	$17^h15^m26^s$	-38°28'	393 / 396	205	
G348.7+0.3	$17^h13^m55^s$	-38°11	393 / 396	207	CTB37B
G349.7+0.2	$17^h17^m59^s$	-37°26'	393 / 396	209	
G292.0+1.8	$11^h24^m36^s$	-59°16'	490	138	
G189.1+3.0	$06^h17^m00^s$	+22°34'	827	122	3C157
G327.6+14.6	$15^h02^m50^s$	-41°56'	1006	176	
G184.6–5.8	$05^h34^m31^s$	+22°01'	1054	121	3C144, Crab Nebula
G130.7+3.1	$02^h05^m41^s$	+64°49'	1181	111	3C58
GRO/RX J0852			~1200		
G120.1+1.4	$00^h25^m18^s$	+64°09'	1572	108	3C10, Tycho's
G4.5+6.8	$17^h30^m6^s$	-21°29'	1604	10	3C358, Kepler's
G111.7–2.1	$23^h23^m26^s$	+58°48'	1658	101	3C461, Cas A, Flamsteed

Table 4.1 – *SNR Candidates for Historical Supernovae*

Notes

1. The date of the SN is a proposed date of explosion of the progenitor star.
2. The Green number refers to the record number in D.A. Green's catalogue[15] of supernova remnants with numbering from first to last.

4.2 Remnants G315.4–2.3 and G320.4–1.2 and the Supernova of AD185

[15] Green, D.A., *A Catalogue of Galactic Supernova Remnants*, 2001 available at http://www.mrao.cam.ac.uk/surveys. Mullard Radio Astronomy Observatory, Cavendish Laboratory, Cambridge, United Kingdom

4.2.1 G315.4-2.3

The remnants G315.4–2.3 and G320.4–1.2 are commonly associated with the supernova of AD 185. There is much debate about whether these remnants are indeed from a progenitor supernova in 185 and whether observations of a supposed supernova in 185 AD by Chinese astronomers was in fact a comet[16].

The remnant G315.4–2.3 (also known as RCW86) has long been associated with SN185, primarily from evidence presented by Clark & Stephenson. The remnant is a complete shell and circular in shape, at x-ray (Piskarski et.al. 1984), radio (Kesteven and Caswell 1987) and also optical wavelengths (Smith 1997).

I.S. Shklovsky (1960) suggested that a Type II supernova may originate from O or B-type stars, and as such, it is reasonable that Type II SNRs would be associated with OB clusters since they are both young in age. Observations of the time verified this idea and Bengt E. Westerlund (1969) suggested that the remnant G315.4–2.3 was associated with the supernova of 185, and in particular associated with an OB cluster near to G315.4–2.3 based on previous work by Hill (1967) and Minkowski (1968), who determined the distance (2.5 kpc). However, Clark and Stephenson (1977) also argued that the OB association could be in the background.

The distance to the OB cluster linked to G315.4–2.3 is consistent with the Σ-D relation for the SNR, although Green (1991) and Strom (1994) have shown this to be unreliable, with the distance suffering an uncertainty of at least a factor of 3. Westerlund's distance is also in agreement with an estimate provided by Rosado et.al (1996) that uses the systematic velocity of

[16] Chin & Huang (1994), *Identification of the guest star of AD185 as a comet rather than a supernova*, Nature, 371, 398

the nebula to determine distance, but this assumes that the supernova was definitely of Type II.

For G315.3–2.3 to be associated with the supernova of 185, it is widely accepted that the supernovae (Pikarski et.al 1984, Long & Blair 1990) would need to be closer than 2 kpc with Long & Blair preferring the distance of 1 kpc. Long & Blair also showed that the width of the Balmer emission line and the velocity deduced from this emission gave an age in the region of thousands of years, again showing the remnants apparent youth, and as expected, the lines are not as wide as those of younger remnants such as Tycho's (1572) and Kepler's (1604) remnants.

From the interstellar absorption of low-energy x-rays from the remnant, x-ray models indicate that the remnant is located at a distance of 1 kpc, agreeing with the Balmer emission line evidence.

Kaastra (1992) analysed the x-ray spectrum of the remnant using the Ginga satellite, and found the spectrum to be in agreement with that of a Type II supernova explosion. Additionally, the spectrum also indicated that the progenitor star would have been in the region of 22 solar masses – a large star – so any supernova would have been clearly visible on Earth. The x-ray model also supported the distance of 1 kpc. Again in common with the 1572 and 1604 remnants, the direction of polarisation of the remnant's magnetic field is radial, further supporting the remnant's youth.

4.2.2 G320.4–1.2 and the Pulsar PSR 1509-58

There has been suggestion and subsequent debate over the past decade that SN185 is more likely to have left the remnant G320.4–1.2 and its apparently associated pulsar PSR1509-58. G320.4–1.2 is a shell type remnant and as with G315.3–2.3, the SNR could be associated with OB stars and was most likely the result of a Type II explosion.

The idea of an association of SN185 with the pulsar was first raised by Thorsett (1992) based on the almost identical ages of the pulsar PSR1509-58 and SN185. This idea was countered by Richard G. Strom (1994) and his arguments will be summarised briefly.

Strom argues that the distance to the object implies the required age of around 2000 years is largely impossible. It is almost certain that the distance to RCW89 portion of the remnant is 4.2kpc – this was obtained by Caswell et.al (1975) who observed the dynamics of HI absorption from the remnant. Also, ROSAT observations show that the HI absorption levels of PSR1509-58 are much greater than those of RCW89 (and hence the pulsar is further away) and Aschenbach (1993) suggests that as such the two objects are not connected. The model of electron density in the Galaxy as provided by Taylor and Cordes (1993) again suggests that the pulsar is much further away than RCW89, at 5.9 kpc. Since the distance is much greater than that of G315.4–2.3, the supernova may not have been seen at all on Earth from the increased extinction.

The pulsar PSR1509-58 is also much less luminous than other pulsars of a similar age, such as PSR 0531+21 (Crab Nebular) and PSR 0540-69. Seward et.al (1983) discussed this and showed that assuming that the pulsar associated with G315.4-2.3 was at a further distance than RCW89, the discrepancy in x-ray luminosity between the three pulsars was much reduced – a distance of 7 kpc giving even greater agreement with the expected luminosity of PSR 1509-58.

This astrophysical evidence suggests that the remnant G315.4–2.3 is the more likely to have been the result of the supernova in AD185. The apparent link between the age of the pulsar associated with G320.4–1.2 seems to be coincidental given the larger distance to the pulsar than would be needed for the supernova to be visible on Earth. Strom also shows that a supernova event at a distance similar to G315.4-2.3 would have been visible on Earth regardless of the type of supernova.

Object	**Distance (kpc)**	**Method of Determination**
G315.4 – 2.3 (RCW86)	1.3	X-ray absorption
G320.4 – 1.2 (RCW89)	4.2	HI kinematics
PSR1509 – 58	5.9	Dispersion Measure

Table 4.2 – *Distances to the Various Objects*[17]

	G315.4-2.3 (Type Ia SN)	**G315.4-2.3** (Type II SN)	**PSR1509 – 58** (Type II SN)
M_V	-18.9	-16.3	-16.3
A_V	1.0	1.0	4.7
m_v	-5.3	-2.7	+4.3

Table 4.3 – *Ground-based visual magnitudes based on distances in Table 3.2*[17]

4.2.3 Chinese Records and SN185

The only record dating from AD185 is from the *Hou hanshu*, specifically from chapter 22 of the astronomical treatise, the treatise having been

[17] Reproduced from Strom, R.G., 1994, *SN185 and its associated remnant PSR1509-58*, MNRAS, 268, L5

compiled by Siam Biao (AD240-306) and later reproduced in chapter 294 of the *Wenxian Tongkao*[18], and translates[19] as:

> "Emperor Ling, 2nd year of the Zhongping reign period, 10th month, day *guihai*. A guest star emerged within *Nanmen*. It was as large as half a mat, with scintillating variegated colours. It grew smaller and in the 6th month of the year after next [*hou-nien*] it disappeared.
> The standard interpretations say this means insurrection. In the 6th year, Yuan Shao, the governor of the Metropolitan Region, punished and eliminated the officials of middle rank. Wu Kuang attacked and killed He Miao, the General of Chariots and Cavalry, and several thousand people were killed"

Note that the record also provides the astrological interpretation and ramifications of the supernova event.

It would be useful to provide a brief breakdown and examination of the translation of this record. The record, and its relation to a supernova, seems to depend on the translation of the term *hou-nien*. *Hou-nien* can either be taken to mean 'the year after next' or as 'next year', the meaning used in later Chinese. It is widely considered, and this is the view taken by Clark and Stephenson, that *hou-nien* was used as 'year after next' in Han Chinese.

The use of *hou-nien* as 'year after next' is also supported by the use of *ming-nien* as 'next year' elsewhere in the *Hou Hanshu*. This was used in various places, usually in the astrological interpretations of events including in the commentary of a comet sighting in AD55. Matthews Dictionary of Classical Chinese also translates *hou-nien* as 'year after next'. The evidence seems to support Clark & Stephenson's and original use of *hou-nien*, as opposed to Chin & Huang's translation of 'next year' an approach that could, cynically, be taken to reinforce their view that the guest star of AD185 was in fact a comet.

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[18] Wenxian Tongkao – '*Comprehensive Study of Documents and Records*', compiled by Ma Dualin in approximately 1280.
[19] Taken from Clark & Stephenson, page 83

If *hou-nien* is taken to mean 'year after next' then this would suggest a duration in visibility of 19 to 20 months with the first sighting on 7th December 185. If the duration is indeed 19-20 months, then this would almost certainly confirm that the guest star was a supernova event. However, several people have argued against this length of duration citing the fact that such duration would require the supernova to reach a peak magnitude that would be almost impossible.

Chin & Huang argue that the guest star was in fact a comet through motion implied by the original record. They provided the following translation of the text:

> "In the second year of the Zhongping reign period, the tenth month, on the day *guihai*, a 'guest star' emerged from the middle of the asterism *Nanmen*. It seemed to be as large as half a *yan*. It displayed the five colours, and *xi* [pleasure] and *nu* [anger]. It decreased gradually in size and brightness. In the sixth month of the next year it disappeared".

Chin & Huang also go on to translate the prognostications of the appearance of the guest star. They also question the usage of *chu* and *zhong*. *Chu* and *zhong* were originally translated as "appear" and "middle" or "within" respectively, although Chin & Huang argue that a definition of *chu*, which appeared in the *Lingtai miyuan*[20] and the *Kaiyuan zhanjing*[21], gives the meaning as *wei dang qu er qu* – "an object should not have left an asterism but did leave". They also claim that *zhong* translated as "through the middle" and as such believe this implies motion. Green & Stephenson counter this with the lack of evidence of similar interpretations in the official astronomical treatises, and that *chu* was also used in a similar context to their original translation in the descriptions of subsequent supernovae in 1006, 1054, 1181, 1572 and 1604. *Zhong* was also used to

[20] *Lingtai miyuan* – "Secret Garden of the Observatory"
[21] *Kaiyuan zhanjing* – "Kaiyuan Treatise on Astrology"

describe the position of sunspots and Green & Stephenson also present further evidence to support their usage of *chu* and *zhong*.

The third argument they present is concerned with the size of the guest star (or comet). Both translations give the size of the object as 'half a *yan*' but disagree on the usage. A *yan* was a bamboo mat and reference to the size of stellar objects as common household items (e.g. melons, papayas etc.) was not unusual, although the use of *yan* is unusual. Chin & Huang postulate that a *yan* could have been a unit of length equal to 9 *chi*, and since *du* and chi are used in place of each other regularly, the guest star was 4-5^{o} in length. Chin & Huang give no evidence for their usage of *yan*, and Green & Stephenson comment that they have found no evidence either. Green & Stephenson also point out that from 200BC, it was standard practice to express the lengths of comet tails in units of either *chi* (1 degree) or *zhang* (10 degrees).

The star was also referred to as *kexing* (guest star) in the original text, not as *huixing* (comet), although Chin & Huang give examples of comets described as *kexing* along with a description of the length of their tail. If the comet were approaching the observer head on during some part of its orbit, then no tail would be visible, and the comet would also brighten as the comet neared the Earth. This would also account for its stationary behaviour and the fact it then left the asterism. If the comet appeared stationary then it is reasonable that since the tail was not visible then it would initially be recorded not as a comet but as a guest star.
However, as the object disappeared gradually and with no evidence of brightening this would suggest the object was not a comet approaching head on. The visibility of a comet for the durations suggested by both Chin & Huang (six months) and Clark & Stephenson (20 months) is unusually long, and the longest comet duration as seen in Ho Peng Yoke's compilation of

East Asian comet and novae sightings was 190 days. This comet was especially bright and the tail was 50 degrees long.

The text describes how the guest star 'scintillated', or in the case of Chin & Huang showed 'pleasure' and 'anger'. The allusion to colour change would imply that the object was not a comet but a stellar object viewed close to the horizon – the increased atmospheric distortion giving rise to the changing colour. The position low in the sky is given since the guest star was observed in the asterism of *Nanmen* ('Southern Gate'), which would have been visible close to the horizon. Clark & Stephenson also point out that the supernova of 1006 was also said to have suffered atmospheric effects from records from Yemen and Europe. Schaefer (1995) also points out that a comet would not be subject to 'scintillation' due to their large apparent size.

It would seem that the claim that the guest star was a comet depends on the translation of three terms in the original text, all of which have less than substantial evidence supporting them. The translations of *chu* and *zhong* have evidence in the form of other records supporting Clark & Stephenson's original usage, and there is no evidence to support Chin & Huang's use of yan to describe the length of the comet's tail. Furthermore, the use of *kexing* instead of *huixing* seems correct despite Chin & Huang's suggestion that other records in the *Hou-hanshu* had similar usages of *kexing* for comet. In a further piece of evidence supporting the supernova event, the guest star was said to fade away, and given its sudden appearance, with no hint of the guest star initially brightening, as would be the case with a comet approaching head on, this would be consistent with a supernova event.

The only other consideration is the visibility of the Nanmen asterism and the guest star. At the time of the first sighting on December 7th 185, the asterism of Nanmen was visible at sunrise, and could be seen in a southwesterly direction. There is little question about the visibility of first sighting, but there lies a problem in the date of disappearance.

During the time of the last sighting, supposedly either July 186 or July 187, there is some doubt about the visibility of the guest star since *Nanmen* sets at around sunset in July. However, *Nanmen* is clearly visible after sunset during June, indicating that the recorded date of July is incorrect in either case. If the duration of the guest star was 6 months, then the error in visibility is one month, and if the duration was, as believed, 20 months, then the record is erroneous by two months. With errors in date recording common, in particular amongst the Astronomical Treatise of the *Hou-hanshu*, an error of two months would not be an impossible hurdle as to the visibility of the guest star; Clark & Stephenson noted that there were errors in the planetary conjunctions in several records during the reign of Xiao Ling (AD168-190).

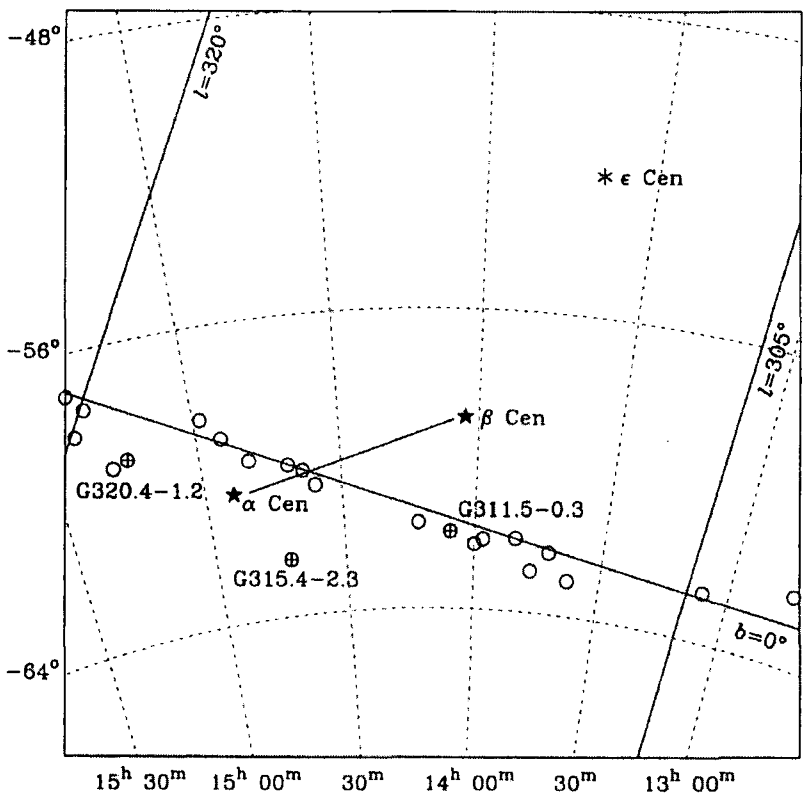

Figure 4.1 – *Remnants in the Nanmen Area*[22]

[22] Reproduced from Green & Stephenson (2002)

4.2.4 Other Remnants in the Nanmen Area

The widely held belief, by Clark & Stephenson, Chin & Huang and Thorsett, is that Nanmen comprised the two stars α and β-Cen. There are a number of SNRs around the immediate area of *Nanmen*. These are shown in Figure 4.1.

Aside from the previously discussed remnants, of which G315.4 – 2.3 is the most likely to have originated from the supernova of 185, there exist three other remnants whose position links them with the supernova, although many of these are too old to be associated with SN185.

The remnant G312.4–0.4 was discovered in 1985 and is estimated to be at a distance of between 3.5 and 6.5 kpc, and although this was derived by Caswell and Barnes (1985) using the unsatisfactory Σ-D method, due to the previously mentioned atmospheric distortions the remnant would need to be closer to be visible on Earth. Although the SNR is of a similar type to the favoured 315.4 – 2.3, the distance would seem to be too great for this to be seen, for either Type I or Type II supernovae. If the supernova resulting in the remnant G312.4 – 0.4 was of Type Ia as thought by Caswell (1985) then a typical Type Ia light curve would not be in agreement with the date of disappearance, whether erroneous by two months or not, and in any case would most likely not be visible on Earth. The Type II (as postulated by Kaastra (1992)) light curve of G315.4 – 2.3 seems to agree with the date of disappearance and would also be visible on Earth.

Since there is firm evidence to suggest that the remnant G315.4 – 2.3 is of a suitable age, distance and location to be the remnant of SN185, then I take the view that the event observed in AD185 was a supernova and the associated remnant is G315.4 – 2.3.

4.3 The Remnant G11.2 – 0.3 and the Supernova of AD386

4.3.1 G11.2-0.3

The remnant known as G11.2–0.3 is located in the constellation of Sagittarius and exhibits a composite radio structure – it is described in David Green's SNR catalogue as a symmetrical 'clumpy' shell. It also appears to have a 65ms central pulsar, PSR J1811-1925, and from HI absorption, its distance is estimated at 5 kpc. In addition, the remnant appears to be young, and is a likely candidate for a historical supernova.

The major piece of evidence supporting the age of the remnant is the presence of the pulsar at the centre of the remnant. Observations have shown that pulsars move away from the point of formation at a rapid rate, and given that the pulsar G11.2–0.3 is at the centre of the remnant, youth is implied. Similarly, its complex shape indicates youth, and such complexity is also seen in both the Crab Nebula and Vela remnants, two other young SNRs. The data from Chandra suggests that the age of the pulsar is consistent with an explosion in AD386, with the shell temperature and x-ray structure suggesting the remnant is around 2000 years old and entering the Sedov stage of its development. Kothes & Reich[23] (2001) combined radio and x-ray data to determine that the progenitor star was of most likely a B-type star and given the distance, altitude and type of the supernova (Type II), there is no suggestion that the supernova would not have been seen on Earth.

[23] R. Kothes & W. Reich, *A high frequency radio study of G11.2-0.3, a historical supernova remnant with a flat spectrum core* (2001), A&A 372, 627

A problem with the apparent youth of the remnant has implications for current understanding of pulsars. Kaspi & Roberts[24] (2001) used the Chandra Advanced CCD Imaging Spectrometer to examine the remnant and found the pulsar was almost at the geometric centre of the remnant. Further work to examine the age of the pulsar was necessary after Japanese scientists used the current spin rate, 14 revolutions per second, to determine its age using existing pulsar models. Using conventional models they showed that the pulsar was in fact 24,000 years old, making it much older than, and seemingly unrelated to the remnant.

This now questions current pulsar models, since the remnant and pulsar almost certainly date from 386AD – Kaspi & Roberts argue that the pulsar must have the same spin rate as when it was formed, and thus our understanding of the early development of pulsars needs modification.

The age of the pulsar is less important than the fact the pulsar is located at the centre of the remnant – this is incontrovertible and is an almost certain indication of youth. Given that the Chandra data indicates an age in accordance with an explosion in 386, then it seems that the remnant G11.2 – 0.3 is the result of SN386.

[24] V. Kaspi, M. Roberts et.al, *Chandra X-ray Observation of G11.2-0.3: Implication for Pulsar Ages* (2001), ApJ, 560, 371.

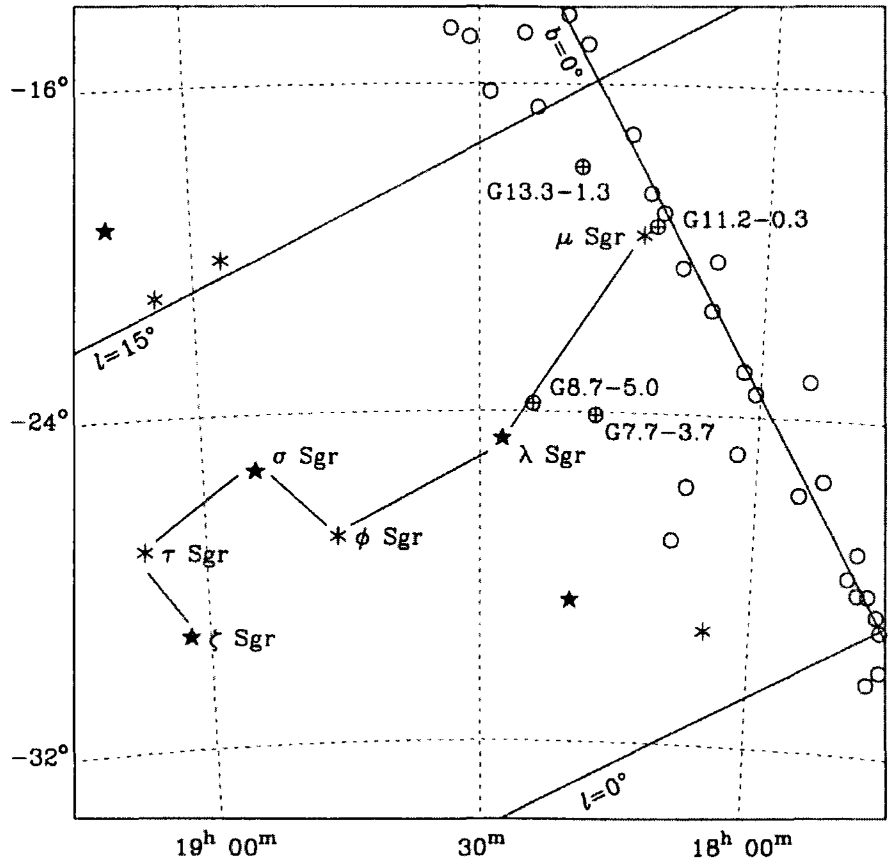

Figure 4.2 – *Remnants in the Sagittarius Region*[25]

4.3.2 Chinese Records

From Chinese records, there was a sighting of a guest star in the region of G11.2 – 0.3 around the time that the remnant is thought to have formed. The record is translated as follows:

> "Emperor Xiaowu of Jin, 11th year of the Taiyuan reign period, 3rd month. There was a guest star in *Nandou* that lasted until the 6th month when it disappeared."

[25] Reproduced from Green & Stephenson (2002)

The record appears in both in chapter 25 of the *Song-shu* and in chapter 13 of the *Jin-shu*, and in a similar vein to the record of AD185, the records are identical. The first sighting was in the period April 15th – May 13th 386, and the last sighting between the dates July 13th to August 10th. This gives upper and lower limits for duration of 60 and 115 days since the sightings are reported by lunar month.

Nandou, or 'Southern Dipper' is located in Sagittarius and was also the 8th lunar mansion – this has implications for the location of the guest star. Green & Stephenson (2002) commented that the use of a lunar mansion in a record was to indicate the range of right ascension for an object. They referred to 19 cometary records where the comet sighted was recorded as being in an asterism that was also a lunar mansion, and given the small number (10%) of asterisms that were used as lunar mansions, they inferred that the use of a *xiu* was intended to indicate the range of right ascension that the object appeared in.

The next earliest record was in AD369, and is also thought to refer to a supernova, although the asterism *Zigong*, near which it was sighted, is not near to Sagittarius, so can be discounted as referring to G11.2 – 0.3. There are no records referring to any events near to *Nandou* from AD 1, and the earliest record of a guest star in *Nandou* was recorded in 45BC. This was of a guest star that appeared to the east of the second star of *Nandou*:

> "Emperor Yuan of Han, 1st year of the Chuyuan reign period, the 4th month. There was a guest star as large as a melon with a bluish-white colour about four chi east of the second star of *Nandou*"

This record is from chapter 26 of the *Hanshu*. There are no other records of guest stars near *Nandou* until a 'fuzzy star' was sighted in *Nandou* between September 3rd and October 2nd 1415 during the Ming dynasty.

The position of G11.2-0.3 is roughly east of the second star of *Nandou*, or λ-Sgr, so positionally, this is not a problem. The reference to the size of the guest star ("as large as a melon") is similar to references to the size of sunspots and suggests the guest star was perhaps 3-4 arcminutes in size.

The record from 45BC is of interest for only the fact that it is around the 2000-year age estimated for the remnant G11.2 – 0.3. There is no indication of the duration of the guest star, nor any description of movement, almost certainly ruling out a comet, so the most likely explanation is the guest star was a nova. The vagueness of the record would suggest the event was not a supernova – nearly all other supernova records are more detailed.

Considering the age of the remnant as estimated by Kaspi & Roberts, and the absence of records for guest star events around the time period the remnant would have formed, it seems highly likely that the record from AD386 refers to the formation of G11.2 – 0.3.

4.4 Remnants in the region of the Constellation of Scorpius

4.4.1 The Bowl of Wei and the Supernova of AD393

There are many interesting remnants in the region of Scorpius and the remnants G348.5+0.1 and G348.7 +0.3, known as CTB37A and CTB37B respectively, are most often linked with historical supernovae.

The remnants in Table 3.1 associated with AD393 are close to the Galactic equator with the constellation of Scorpius also having a small galactic latitude. The major problem with isolating a single remnant resulting from an explosion in 393 is the multitude of remnants in the Scorpius area. Hence it is difficult to isolate one or two outstanding candidates and all must be considered within reason. For this reason, it is easier to verify the reported explosion of AD393 by first considering the Chinese record from this time.

As Clark & Stephenson report, there are two almost identical records referring to a supposed supernova in AD393. The only difference between them is the astrological interpretation. The event is recorded in the *Songshu* and the *Jinshu*, and it is the *Jinshu* record that is more detailed. A translation of the sighting is presented below:

> "Emperor Xiaowu of Jin, 18th year of the Taiyuan reign period, 2nd month. There was a guest star in the middle of *Wei* that lasted until the 9th month when it was extinguished"

Clark & Stephenson prefer the translation of the term *zai Wei zhong* as "within *Wei*" rather than "in the middle of *Wei*". The use of this term is useful as it indicates that the guest star was seen in the constellation of *Wei* rather than in the lunar mansion region of *Wei* (in a similar vein to the record of AD386). Note also the use of *zhong* as within, in contrast to the Chin & Huang interpretation of the supernova record of AD186 (section 3.2).

In a brief aside, the *Jinshu* adds extra detail about the astrological ramifications of the sighting. It says:

> "The standard interpretations say this meant war and death at Yen. During the 20th year [AD 395/396] Mujong Chui and Xi Bao attacked (the State of) *Wei*, but were defeated. More than 10,000 people were killed. During the 21st year [AD 396/397] Chui died and his state was ultimately ruined"

The *Songshu* does not go into as much details as the *Jinshu*, and only mentions "the standard interpretations meant war and death". Note that at the time of disappearance, *Wei* would have been invisible, having set before sunset. Errors in recording of date where only the lunar month is given are frequent in Jin records (of which the Jinshu record is one) and Clark & Stephenson allude to many planetary records that also exhibit such errors. If the 8th month is taken instead of the 9th month, as Clark & Stephenson suggest, the guest star would have been visible for around 200 days.

Whiteoak & Green[26], who concluded there might be 15 such SNRs in the Scorpius region, conducted a comprehensive study of the area around Scorpius (and the southern sky in general). Between the galactic latitude 0° and 3° and the longitudes 0° and 340°, there are 33 SNRs, these all being catalogued in David Green's SNR catalogue. These are listed in Appendix 1; this also includes the reference number for Green's catalogue.

As we have more specific evidence as to the whereabouts of the supernova of AD393, the list of 33 SNRs can be trimmed somewhat and the most likely SNRs to have resulted from a historical supernova are listed in Table 3.4. If we assume to begin with that the use of *zhong* refers to "within", we can isolate 12 remnants within *Wei*, with the remnants at l = 343.1° and l = 351.7° being the two limits of Galactic longitude required, and discount any SNRs with galactic latitude greater that 1°, the list of candidates for the supernova of 393/396 are listed in Table 4.4

[26] J.B.Z. Whiteoak & A.J. Green, *A Comprehensive Southern-sky Supernova Survey using the Molongo Observatory Synthesis Telescope (MOST)*, (1996), A&A Suppl., 118, 329.

Table 4.4 – *Candidates for SN393 within the Asterism of Wei*

Remnant	Type	Distance (kpc)	Green[27]
G343.1-0.7	Shell	(6.9)	200
G344.7-0.1	Shell		201
G345.7-0.2	Shell	(25.4)	202
G346.6-0.2	Shell	(8.2)	203
G347.3-0.5	Shell?	~6	204
G348.5-0.0	Shell	(7.2)	205
G348.5+0.1 (CTB37A)	Shell	10.2 ± 3.5 kpc	206
G348.7+0.3 (CTB37B)	Shell	10.2 ± 3.5 kpc	207
G349.2-0.1	Shell	(17.2)	208
G349.7+0.2	Shell	18.3 ± 4.6 kpc	209
G351.2+0.1	Composite?		211
G351.7+0.8	Shell	(6.7)	212

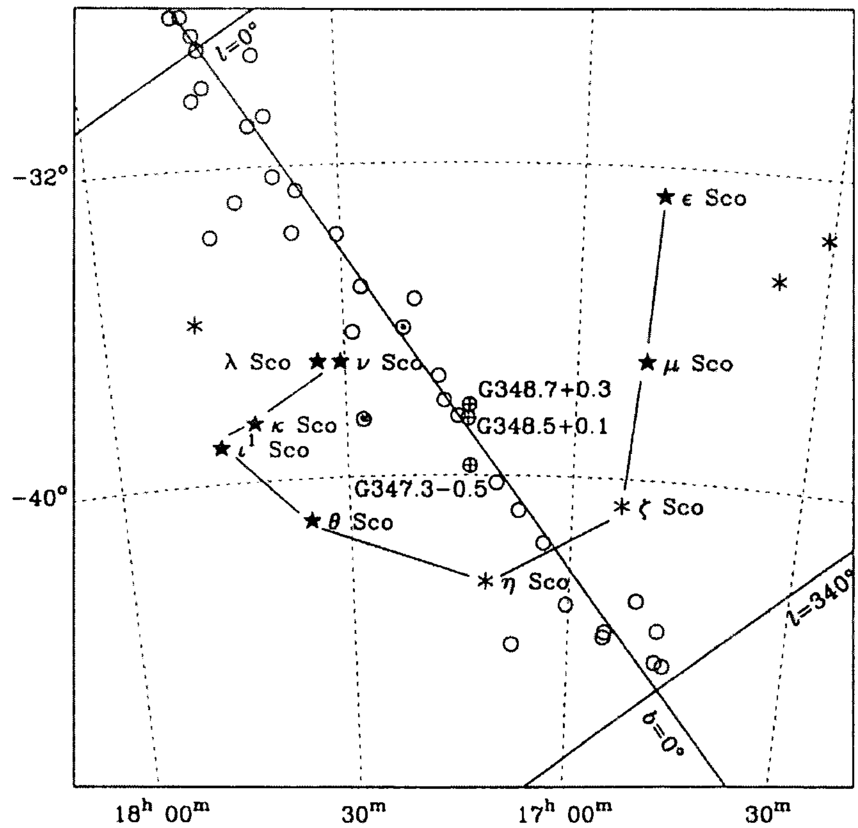

Figure 4.3 – *Remnants in the Scorpius Region*[28]

[27] This number refers to the number in David Green's SNR catalogue.
[28] Reproduced from Green & Stephenson (2002)

The distance estimate references are taken from Caswell et.al.[29] and those in parentheses from Case and Bhattacharya[30]. Note that Whiteoak & Green produced an updated catalogue in 1996 but the distances obtained remained the same as for Caswell et.al.

It could be argued that the most likely candidates will be of shell type, as seen in the previous SNRs discussed. This would discount G351.2+0.1 and given the uncertainty surrounding its structure, G347.3-0.5 also.

To compound the problems surrounding the identification of a suitable SNR is the lack of distance information for all but three of the remnants. This is due to the majority of remnants being too dim for accurate HI absorption line measurements, a good indicator of distances to SNRs, and due to its inherent inaccuracies the Σ-D relation is no longer used for distance estimation. Although we could assume that the supernova would have left a shell remnant, this does not help as all but one (G351.2+0.1) are thought to be of shell type.

Case & Bhattacharya[23] suggested an alternative Σ-D relation, which is claimed to be more accurate. From the increased number of SNRs discovered and more modern rotation curve models, they recalibrated the Σ-D relation and offered estimated distances to objects for which distances were unknown. Assuming their revised relation is valid (a detailed discussion of this is beyond the scope of this thesis) the distances could have significant bearing on the candidature of the various remnants for the supernova of 393. These distances are given in parentheses in Table 3.4.

[29] J.L. Caswell et.al, *Neutral hydrogen absorption measurements yielding kinematic distances for 42 continuum sources in the galactic plane* (1975), A&A, 45, 239

[30] G.L. Case & D. Bhattacharya, *A New Σ-D Relation and its Application to the Galactic Supernova Remnant Distribution* (1998), ApJ, 504, 761.

It could also be assumed that the remnant, being of youthful age, would have a reasonably high surface brightness, and if this is the case then this reduces the number of candidates. Clark & Stephenson suggest a distance of 5 to 6 kpc would have been the maximum distance the supernova could have been at to be visible.

Of the SNRs that have had distances estimated by Caswell et.al, none of them are within a suitable distance range for the supernova to have been visible on Earth, especially G349.7+0.2 at a distance of ~18 kpc. Given that the atmospheric light absorption would have been reasonably high at the location of observation, and also the low galactic latitude, we can almost certainly discount G349.7+0.2 would have been almost invisible at the time of supernova.

G344.7-0.1 can be discounted as it is too faint and given its small angular size is most likely at too great a distance for the supernova resulting in its formation to be seen. This is also the case for G346.6-0.2, G349.7+0.2 and these along with G345.7-0.2 can be discounted from their high estimated Case & Bhattacharya Σ-D distance.

The structure of G347.3-0.5 is uncertain, and although it could be of shell type, no distance is available and at this stage it would be assuming a lot to include it as a viable candidate. It was suggested to be the remnant of AD393 by Wang et al. (1997) who originally thought it to be at a distance of around 1 kpc. Slane et al. (1999) suggest a greater distance of around 6 kpc from measurements of surrounding HII clouds. Green & Stephenson (2002) argue against the association of this remnant with AD393 given that the expansion rate of the remnant would be too great for this date of explosion.

Assuming that the CTB cluster is also at too great a distance, G348.5-0.0, CTB37A and CTB37B can be discounted for now, although these remnants will be discussed later.

This leaves remnants from its shortlist – G343.1-0.7, G348.5-0.0 and G351.7+0.8. Interestingly, the revised Σ-D relation gives the distance to G348.5+0.1 as 7.2 kpc, which indicates it is either not part of the CTB complex (although close), there is significant distortion from the surrounding sources affecting observations of the remnant or the Σ-D relation is completely wrong. It is unlikely that the Σ-D relation is drastically wrong – as it is an estimate you would expect some deviation from the actual distance.

For now, we can assume that G348.5-0.0 is at approximately the distance given by Case & Bhattacharya's estimate. The distance to the remnant is only just greater than the distance recommended by Clark & Stephenson, and given that the CTB complex is suggested by Clark & Stephenson as a possible remnant of SN393, we could argue that a distance of 7.2 kpc is not too great.

The same can be said for G351.7+0.8 and G343.1-0.7 and these are even closer to Clark & Stephenson's threshold distance, at estimated distances of 6.9 and 6.7 kpc respectively. Clark & Stephenson discounted the remnants G343.1-0.7 and G351.7+0.8 presumably on grounds that they were too far away from the bowl of *Wei* to be considered "within". However, I would argue that although they would be at the limits of the bowl, they are sufficiently close enough to *Wei* to be considered "within".

Returning to the remnants in the CTB area, the remnants CTB37A (G348.5+0.1) and CTB37B (G348.7+0.3) were originally considered as possible remnants by Clark & Stephenson. Although it would appear that the distances are too great (remembering that the distance was not estimated from Σ-D but calculated from MOST observations) the remnants are still worth looking at. The three remnants in the group, including CTB37A and B and G348.5-0.0 are in very close proximity and as such there is some difficulty in observing them individually. CTB37A appears to be the most luminous of the three objects, but again, it is difficult to be certain of this given the proximity of G348.5-0.0. It is argued that any of these remnants could have been resultant of SN393, but the greater distances of CTB37A and B suggest otherwise, with only G348.8-0.0 estimated to be near enough from revised Σ-D calculations. Any association with AD393 of any of these three remnants should be treated with caution due to the uncertainty surrounding the distance and observations.

In summary, there is much speculation surrounding the remnants in the bowl of *Wei*, with only a few realistic candidates. From the revised Σ-D distances I would suggest that further investigation would be appropriate given both the new distances suggested by Case & Bhattacharya and the suitable angular sizes and brightnesses of G343.1-0.7 and G351.7+0.8, and that the two remnants should be considered as candidates for the remnant of SN393.

4.4.2 *Other Records Relating to the Immediate Scorpius Region*

As we have so many possible young SNRs, it may be useful to search for more records referring to the asterism of *Wei*. A quick search reveals that there are records referring to *Wei* in AD708, 1203, 1240, 1437, 1600 and 1604. Many of these records refer to *Wei* the lunar mansion rather than *Wei* the asterism. For example, the record from AD708 states:

> "Emperor Zhongzong of Tang, 2nd year of the Jinglong reign period, 7th month, the 7th day. There was a fuzzy star between *Wei* and *Mao*"

Wei and *Mao* (lunar mansions 17 and 18 respectively) were mentioned as an indication of area. As no positional information is given other than that the guest star was sighted between *Wei* and *Mao*, the record would not refer to any of the previously mentioned SNRs.

A record from 1203 has been suggested as referring to a supernova but refers to the guest star as appearing "in the southeast within the lunar mansion *Wei*", and as such no exact position is given. If this indeed does refer to a supernova, then an initial search could be centred around the remnants in the bowl of *Wei*, but this would be merely a starting point and there is no evidence to suggest these SNRs are any more likely to be resultant of a supernova in 1203 than any others in the *Wei* lunar mansion area. This is also the case for the record of 1230, where the *Songshi* relates the sighting of a guest star as having "emerged in lunar mansion *Wei*".

A record from Korea dated 1600 reads as follows:

> "33rd year of King Sonjo, 11th month, day *jiyou*. A guest star appeared in *Wei*. It was larger than the Fire Star [*Huoxing*] in *Xin*. Its colour was orange and it glittered"

This record is more promising as regards position. The record informs us that the star appeared in *Wei*, and as it does not mention the term "lunar mansion" it is possible that the guest star did in fact appear in the immediate region of the asterism *Wei*. Given that the record refers to the Fire Star, or Antares, as it is known in occidental astronomy, as a comparison for size, this suggests that the guest star was also in the proximity of Antares/Scorpius.

Given the apparent magnitude of Antares, the 15th brightest star in the sky, is +0.96, it would not have been exceptional for a nova or supernova to be brighter. The 'glittering' can be attributed to atmospheric absorption and the apparently low galactic latitude. It is by no means certain that this record places the guest star in *Wei*, or that it refers to a supernova at all. No time of disappearance is given so we do not have any evidence of duration and hence any link to the remnants in *Wei* as previously discussed cannot be verified.

There are many records relating to a supernova in 1604 and it is almost certain these refer to the supernova observed by Kepler. This will be discussed in a later section.

Although not of direct interest to this thesis as the record is from Korea, a record dating from the time of King Sejong (March 11th 1437) refers to a guest star appearing in *Wei* of duration 14 days.

> "19th year of King Sejong, 2nd month, day *yichou*. A guest star first appeared between the second and third stars of *Wei*. It was nearer to the third star and separated from it by about a half a *chi*. It lasted 14 days in all".

The first point to note is the more or less exact position given by the record. The record states that the star was located between the second and third stars of *Wei* – μ-Sco and ε-Sco. This would certainly aid identification of a remnant if this is a supernova. However, there are no suitable remnants in this area – understandable given the high galactic latitude of this position. Given the short time period (14 days) it is more likely that the guest star is a nova.

The only situation in which it could be considered a supernova is if it the progenitor star was at such a distance that the initial magnitude of the supernova could be seen with the unaided eye and if the supernova was of Type I. In this case the star could conceivably appear and disappear within 14 days, with the peak magnitude after 7 days or so, and the star dimming to below its initial magnitude after 14 days. Even then this could be too short a time scale for a supernova event but given the low position in the sky it is possible that the supernova could disappear from view after 14 days.

It is possible that this record could refer to a supernova, but the evidence leans towards a nova given the short duration of the sighting.

4.5 GRO/RX J0852 and the Case of the Missing Supernova

Recent research has suggested that a supernova exploded some 700 years ago – not all that extraordinary save for the fact there are no direct records, either in European or Asian astronomy. The remnant of this supernova would be sufficiently close to rival the Moon in brightness.

4.5.1 Astrophysical Evidence for the Age of GRO/RX J0852

The major piece of evidence supporting the youthful age of the SNR GRO/RX J0852[31] is the presence of two radioactive metallic elements, Ti^{44} and Al^{26} in the emission spectra of the remnant as observed by COMPTEL[32] and ROSAT[33]. Chen & Gehrels[34] (1999) presented evidence that a $15M_{\odot}$ star was the progenitor of the supernova, which was highly likely to have been a Type II supernova based on measurements taken by Iyudin [35](COMPTEL, gamma rays) and Aschenbach (ROSAT, x-rays).

[31] This is a condensed name; the remnant is known as either GRO J0852-4342 or RX J0852.0-4622.
[32] A gamma ray telescope based at NASA's Compton Gamma Ray Observatory.
[33] The ROentgen SATellite, a German operated x-ray satellite. See *http://heasarc.gsfc.nasa.gov/docs/rosat* for further information about the ROSAT mission.
[34] W. Chen & N. Gehrels, *The Progenitor of the New COMPTEL/ROSAT Supernova Remnant in Vela* (1999), ApJ, 514, L103
[35] Iyudin, A.F. et al., *Emission from 44Ti associated with a previously unknown Galactic supernova*, (1998), Nature, 396, 142

Chen & Gehrels reached this conclusion based on a number of observations. The first, as previously stated, was the presence of Ti^{44} and Al^{26} - these elements had not been observed before in the same remnant. Astronomers had previously thought the Al^{26}, a radioactive element with a half-life of 700,000 years, had originated in the nearby Vela supernova remnant. Given the half-life of the titanium present is 60 years, the initial indication is that the supernova remnant must be close enough to detect the tiny quantities of Al^{26} present and recent enough to account for the presence of Ti^{44} isotope.

The remnant had not been previously detected due to the presence of the older (11,000 years) Vela supernova remnant – observations in the higher gamma-ray region only recently detected the abundance of Ti^{44}, of which the Vela remnant had long since lost.

Chen & Gehrels attributed the remnant to a Type II supernova due to the expansion speed of the remnants shell – the shell is not expanding at a high enough velocity for it to be attributed to a Type Ia supernova, and if it were the supernova remnant would have to be in the Sedov-Taylor phase, which it is not. Given the conclusion that the star was caused by a Type II or Type Ib/Ic supernova, Chen & Gehrels presented two possible distances.

They initially estimated the expansion speed of the shell as 2000 km s^{-1}, as calculated from preliminary x-ray observations. If the expansion rate is indeed around this rate, then the distance would be around 150pc and the supernova of Type II as expected. However, if the expansion rate is greater than 3000 km s^{-1}, then a distance of 250pc would be needed and a Type Ib or Ic supernova (with an initial mass of $< 10\ M_{\odot}$) would almost certainly have caused the presence of the remnant. As yet, the exact type of the supernova is uncertain as more accurate measurements of the expansion speed of the shell are needed.

If the current expansion speed is less that 2500 km s^{-1}, the supernova would have had to have occurred in a region of high-density gas to account for the slow expansion. Type Ib and Ic supernovae would require an even higher density of gas to account for the slow expansion given that they are more energetic. A search for such a high-density region showed the only possible region at the required distance and direction was the Gum Nebula. This largely consists of low density gas, but does contain some high density regions at the required distance although these are not dense enough for the supernova models, with a Type II supernova requiring a density of > 100 cm^{-3} (and Types Ib and Ic requiring greater) and the densest region of gas having a maximum density of less that 2 cm^{-3}. However, Chen & Gehrels argue that since the Gum Nebula was formed by a supernova event, there may be large densities of gas at the edges of the Nebula that could provide the required high densities of gas.

A survey by Murphy & May (1991) showed there are complex molecular cloud structures in the region of Vela and there was one such region that could provide the dense area of gas required. However, data shows that the cloud appears to be undisturbed, as would be expected by a supernova event, and they are slightly too distant, at 1-2 kpc. Even if the distance estimates were inaccurate, the cloud density is too low to rule out all but a Type II explosion.

Given the absence of suitable high-density gas to account for the low expansion speed of the remnant, Chen & Gehrels favour a Type II supernova and an age of ~700 years at a distance of 150pc. However, their findings were based on a relatively simplistic model, and further observations will be needed to confirm the remnant's age without doubt.

Chen & Gehrels estimate of distance and age imply that the supernova would have been near impossible to miss on Earth, although Aschenbach et al. (1999)[36] suggest that the supernova may not have been observed if the supernova were sub-luminous and had a short peak-plateau duration. Additionally, Aschenbach et al. estimated an age of ~680 years and a distance of ~200pc for the remnant and suggest that the remnant may have been visible 700±150 years ago. This gives a wider range of dates for the supernova event although given the rough agreement between Aschenbach et al. and Chen & Gehrels the discussion will centre on supernovae around the 13th Century.

However, there appear to be no suitable records relating to this event dating from either the 13th Century or from the wider age ranges suggested by either Aschenbach or Chen & Gehrels.

4.5.2 Where Are the Records for the Supernova of the 13th Century?

Given the proximity to the Earth, the supernova would have been extremely bright and visible for an appreciable length of time. This raises the question as to why no records exist, not only from China, but from anywhere in the world.

There are no records from East Asia at all, either from Korea or China. This firstly raises the question as to whether the region of sky was visible to the Chinese as that time of year, bearing in mind that the supernova would have been close enough for it to be visible during the day. The remnant GRO/RX J0852 is in the region of the occidental constellation Vela ("The Sail"), an unremarkable constellation aside from the presence of the brightest Wolf-Rayet star, an optical pulsar and a variable star that could be the prototype of a new class of variables.

[36] B.Aschenbach, A.F.Iyudin & V.Schönfelder, *Constraints of age, distance and progenitor of the supernova remnant RXJ0852.0-4622 / GRO J0852.0-4422* (1999), A&A, 350, 997

The constellation of Vela, situated close to the Galactic equator, was visible for the most of the year at some time during the night. Such was the proximity of the supernova to Earth that the supernova would have been visible in the day also. There is no possibility that the supernova would have been obscured for extinction reasons, even with its proximity to the Galactic equator.

For the purposes of this thesis, it would be more appropriate to investigate the lack of Chinese records rather than suggest reasons for the lack of European records. At the time of the supernova, which we will assume was around 1200AD, there was much upheaval in China. It was approaching the time of the fall of the Jin dynasty in 1233 with the Jin experiencing poor relations with the Southern Song, with whom they existed side-by-side. The Jin had allied themselves to the Western Xia, increasing their political strength and demanding a degree of peace between themselves and the Song.

Historically, the Jin were enemies with their northern neighbours, the Mongolians. In fact, the area controlled by Jin was surrounded by the Xia to the west, Mongolia to the north and the Song to the south. The Jin attacked the Song to the south, which resulted in their northern power base being exposed to attack from Mongolia. A more sensible step may have been to unite China and resist Mongolia rather than fight the Song alone. In around 1215 and following an attack from lead by Genghis Khan, the Jin moved their capital from Beijing (or *Zhongdu* as it was known) to Bianjing (Kaifeng City, Henan Province) and tried to increase their territory to the south to make up for their losses to the Mongols in the north. In 1233, a Mongolian army captured Bianjing, and with the assistance of the Song, overthrew the Jin dynasty. Following the death of Genghis Khan, his grandson (as Kublai Khan) founded the Yuan Dynasty in 1271 with their capital at Beijing, with the Mongols adopting a Chinese-style system of rule.

This period of war and chaos could account for the lack of a supernova record from this time. Three Chinese guest star records exist from 1203 to 1240, and all are recorded in the *Songshi*, suggesting the Song were still observing astronomical events (all these records are in the region of lunar mansion *Wei* so are of no interest). The lack of similar records from the time of the Jin suggests that the Jin were not concerned with astronomy at that time; after all they were fighting a war! The movement of the capital around the time of 1215 could account for the lack of records from the Jin and there is the possibility they were destroyed or left at the time of the move, if the observations were even made.

Presumably, the movement of the capital would have required a new observatory to be built, and there is no indication that there was a working observatory at the new capital. This delay could account for the lack of a record, although considering the brightness of the supernova, one would have thought the event would have been recorded, observatory or no observatory.

However, this is all speculation and there are no hard facts surrounding the loss of records. It seems likely that the lack of records from the Jin was due to the numerous battles being fought by them, although this does not explain the lack of records from Korea or the Song. It seems strange that no records exist from either the Eastern or Western cultures and raises the point that if there was a supernova in 1200 as observations suggest, it must have been invisible for some reason.

4.6 The Remnant G292.0+1.8

4.6.1 Astrophysical Evidence for the Properties of G292.0+1.8

G292.0+1.8 is young, oxygen rich synchrotron nebula with a central pulsar estimated at 1,600 years. Located near to the (occidental) southern constellations of Centaurus and Crux, the remnant is one of the ten brightest supernova remnants in the galaxy. First observed in 1970[37] in the radio band, the remnant comprises a shell of rapidly expanding gas and contains elements such as oxygen, neon, silicon, magnesium and sulphur, and is between a shell-type and Crab-like remnant in structure.

Using x-ray observations, it has been seen that G292.0+1.8 is similar to the Crab Nebula in structure and it is believed that the presence of elements such as oxygen indicate the core collapse of a massive star, and is only the third known oxygen rich remnant in the galaxy, the others being Puppis A and Cassiopeia A. From its structure, it is thought to to be the same type as, although slightly more evolved, the remnant Cassiopeia A. This provokes much interest in itself since oxygen-rich nebulae are thought to be responsible for planet formation.

An x-ray study of G292.0+1.8 by Camilo[38] et.al (2002) revealed the presence of a pulsar within the remnant using the Parkes radio telescope. This followed the discovery of a region of 'hard' x-ray emission in 2001[39]. The detected pulsar has a period of 135 ms and derivative of 7.4×10^{-13}, giving a theoretical age of 2900 years. This is greater than the age derived by Slane et al., and can be explained in a similar way to the remnant linked

[37] P.A. Shaver, W.M. Goss et al., *Optical identification and spectrum of the supernova remnant G292.0+1.8* (1970), MNRAS, 188, 357
[38] F. Camilo et al., *PSR J1124-5916 : Discovery of a Young Energetic Pulsar in the Supernova Remnant G292.0+1.8* (2002), ApJ, 567, 71
[39] J.P.Hughes et al., *A Pulsar Wind Nebula in the Oxygen-rich Supernova Remnant G292.0+1.8* (2001), ApJ, 559, 153

with the supernova of 386AD (§4.3) in that the pulsar may not have slowed significantly since its formation[40]. The youth of the system is further indicated by the coincidence of the pulsar and the geometric centre of the nebula.

The distance to the remnant is generally accepted to be ~5 kpc, from both spectral analysis and estimations using the observed pulsar characteristics – this is a useful in terms of identifying any historical record as it suggests the supernova would have been observed on Earth.

4.6.2 Chinese Records and Visibility

The constellation of Centaurus, near to which the remnant G292.0+1.8 is located, is barely visible near to the horizon north of Henan province (including Beijing). Given the fact that the remnant would have been below the horizon for much of the year, this accounts for the lack of Chinese records –the time of explosion the remnant would have been invisible to the Chinese. The approximate declination limit of visibility is –55°, and since the remnant has a declination of -59°16' the area of sky concerned is, and was, not visible to the Chinese.

[40] V.M. Kaspi et al., *Chandra X-Ray Observations of G11.2-0.3: Implications for Pulsar Ages* (2001), ApJ, 560, 371

4.7 The Remnant G189.1+3.0/IC443 and a Supernova in AD837

4.7.1 Introduction

The remnant G189.1+3.0, or IC443, is located near to the constellation of Gemini. IC443 has been linked with a possible historical supernova, and research has suggested that the remnant has an age compatible with a supernova in the 9th Century AD. There have been numerous investigations into the structure and evolution of IC443, particularly in the x-ray band including comprehensive studies by Petre et.al[41] (1988) and Aschenbach[42] (1994). The position of the remnant also coincides with an unidentified gamma ray source and this is thought to be either an interaction between supernova emission and cosmic radiation or an as yet unknown neutron star.

The association between this and a supernova in 837AD has been suggested by Shajn & Gaze (1954) and Shklovsky (1954) due to the coincidence in position between IC443 and guest stars sighted in 837AD, although new evidence centring around the discovery of a central pulsar throws this association into doubt, even before considering any historical records. Again before the discovery of a central pulsar, Xi (1954) argued against this idea, as have Stephenson & Green (2002), instead suggesting that the guest star records from 837AD referred to Halley's Comet.

Wang et al.[43] (1992) put forward an explanation accounting for the presence of both Halley's Comet and a guest star in 837AD. X-ray observations using the Ginga satellite by Wang et al. showed the presence of x-rays generated by the heating of plasma by a shock wave. The velocity of the shock wave causing the heating was calculated to be 3×10^5 ms^{-1}, and this in turn gave

[41] R. Petre et al., 1988, ApJ, 335, 215
[42] B. Aschenbach & I. Asaoka, 1994, A&A, 284, 573
[43] Wang et al., *Hard X-rays from the Supernova Remnant IC443* (1992), PASJ, 44, 303

the age of the remnant to be 1000~1400 years, in agreement with a formation in 837AD – the previous suggested age for IC443 was 10^4 years.

4.7.2 Guest Star Records of AD837

Two records from the *Xin Tangshu*[44] read as follows:

> "Emperor Wenzong of Tang, 2nd year of the Kaicheng reign period, 3rd month, day *jiashen*. A guest star emerged below *Dongjing*. In the 4th month, on day *bingwu*, the guest star below *Dongjing* disappeared." (April 29th 837)

> "Emperor Wenzong of Tang, 2nd year of the Kaicheng reign period, 3rd month, day *wuzi*. Another guest star emerged within *Duanmen* near *Pingxing*. In the 5th month, on day *guiyou*, the guest star within *Duanmen* disappeared." (May 3rd 837)

Similar records were also found in the *Wenxian Tongkao*. The April 29th record states that a guest star appeared in *Dongjing* (in Gemini) on April 29th, 837 and disappeared on May 21st. This is seemingly enough evidence for some authors to consider the sighting as a supernova, for a supernova in 837AD appears in the catalogues of Biot, Williams, Lundmark, Ho and Xi & Bo. Green & Stephenson reject this guest star as a mere fast nova, given its duration of 22 days. The second record was also dismissed as a nova by Green & Stephenson due to its high galactic latitude (in the constellation of Virgo) and the lack of supernova remnants thereof.

Wang et al. also provide an unnecessary explanation countering any confusion between the guest stars and Halley's Comet. A record, translation from Wang et al., from the *Xin Tangshu* recounts a sighting of Halley's Comet:

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[44] Xin Tangshu – "*New History of the Tang Dynasty*"

"On April 28th, it was about 3ft long. It then went out of sight in Leo"

Since the comet would have had to travel from Leo to Gemini to be confused with the guest star, a clearly impossible situation given the location of both constellations (the separation is some 45°), it seems strange that Wang et al. would suggest there could be confusion.

4.7.3 Astrophysical Evidence Contradicting the Link Between IC443 and a Supernova in AD837

Despite the various arguments between the positions of Halley's Comet and the appearance of a guest star in Gemini, observations from the Chandra[45] X-ray Observatory showed that the source of hard x-rays discussed by Wang et al. was in fact a comet-shaped nebula with an associated neutron star. The shape of the nebula is caused by the supersonic motion of the neutron star, which causes a bow shock and synchrotron tail. The speed of the neutron star and the properties of the pulsar (with period 145ms) indicate an age of 30,000 years – very different to the suggested age of 1000-1200 years.

However, despite the evidence suggesting a link between the neutron star and IC443, there are a number of inconsistencies – namely the lack of radio pulsations and the direction of the comet tail. If the neutron star were to have originated from the supernova that also caused the formation of IC443, the pulsar should have been formed at the geometric centre of IC443. However, the 'tail' of the nebula surrounding the pulsar does not point towards the centre of IC443 as expected, directed northeast instead of north. This has been tentatively dismissed as disproving the link between the pulsar and IC443 due to the complex structure of the IC443 region – it cannot be proven yet that the pulsar definitely originated at the geometric

[45] C.M. Olbert et al., *A Bow Shock Nebula around a Compact X-Ray Source in the Supernova Remnant IC 443* (2001), ApJ, 554, L205

centre of the remnant. Similarly, it has been suggested that the pulsations from the pulsar do not lie in our line-of-sight.

Although there are reasons to link the remnant IC443 to a possible supernova in 837AD, and also strong astrophysical evidence to suggest IC443 is much older than required for such a link, more research needs to be done to further prove, or disprove the various ages suggested for the remnant. Whilst the records from 837AD may indeed describe a supernova, without further and definite evidence to verify the age of the remnant, it would be foolish to further debate the link between the remnant and the records.

4.8 3C58 / G120.1+1.4 and the Supernova of 1181

The remnant 3C58 has been associated with the reported supernova of 1181AD recorded in East Asia, including three independent records in China. Of the remnants in the area described by the records, the asterism *Chuanshe*, only one appears to be a suitable candidate, and this is 3C58. Much research has been conducted into this supernova and the link between 3C58 and the various records is certain. For this reason the following discussion of the supernova will be brief and only consider the main points of interest.

4.8.1 The Remnant 3C58

3C58, or G120.1+1.4, is located in the constellation of Cassiopeia and is of filled-centre type. The star has been used to calibrate the Σ-D, although the distance used to do this is now thought to be inaccurate and this could account for some of the discrepancies encountered when the Σ-D method of distance determination has been used in the past.

This distance has thus been the subject of much debate. Initially, the distance of the remnant was thought to be 8 kpc, a distance which Clark & Stephenson used in their investigation into SN1181, and this distance requires the supernova to be brighter than –19 magnitude and this in turn requires the supernova to be of Type Ia. However, the distance estimates were revised by Green & Gull[46] (1982) with a new distance of 2.6 kpc suggested from galactic rotation models. This, obviously, would not necessitate the high magnitude for visibility on Earth. Use of more refined galactic rotation models has resulted in the current estimate of 3.2kpc, and HI absorption measurements confirm this. Huang[47] (1986) argued that 3C58 could not be the remnant of SN1181 based on the absolute magnitude of the supernova although this was based on previous distance estimates, and their arguments are invalid when the revised distance of 3.2 kpc is used.

The structure of the remnant gives us strong clues as to the type of supernova that resulted in its formation. The remnant is highly magnetically polarised, giving it its characteristic filamentation and a strong central emission source was found in 1995[48], although there is no indication that this is a pulsar. The high concentration of nitrogen in the remnant indicates that the progenitor star lost some of its mass before supernova, and this also indicates that the supernova was of Type II-L - the measurements of expansion velocity (5.5×10^6 ms^{-1}) and required magnitude (~ -2) are in agreement with a supernova of this type as well as the observed duration of the supernova (185 days).

[46] D.A. Green & S.F. Gull, *A Revised Estimate of the Distance to 3C58* (1982), Nature, 299, 606
[47] S. van den Bergh, *Classification of Supernovae and their Remnants* (1988), 327, 156
[48] D.J. Hefland et al., *ROSAT X-ray Observations of 3C58 showing a central source of emission, though no evidence of periodicity* (1995), ApJ, 453, 741

4.8.2 Chinese Records from 1181

As with the time of the possible supernova of 1208, China was divided in two, between the Song and Jin. Unsurprisingly, the most thorough account of the supernova of 1181 comes indirectly from the Song dynasty and is recorded in the *Wenxian Tongkao*[49]:

> "Chunxi reign period, eight year, 6th month, day *jisi*. A guest star appeared in *Kui* lunar lodge, invading *Chuanse*. The divination was 'A guest star appears in Heaven and is abnormal. The various houses it enters indicate fortune or disaster. When the star is large the event will be great and the calamity profound. When the colour is white, its allocated territory will experience war and death'. Now this guest star has appeared at the edge of *Ziwei* and the stars of *Chuanshe*. It is appropriate to prepare for a messenger of treachery from the border barbarians invading our territory. It is also said that what appears in *Kui* creates war, while treacherous ministers deceive and confuse the emperor. Therefore the messenger of the Jin Slaves comes to wrangle, submitting letters and gifts.
>
> "On day *jiaxu* the guest star guarded the fifth star of *Chuanse*. Ninth year 1st month, day *guihai* : from this time the guest star was no longer seen. From the previous year, 6th month, day *jisi* until this time was a total of 185 days; then it faded and hid itself. At this time the Slave messenger had been in the guest house a long time and at this point he departed."

This record is interesting (aside from the astronomical perspective) in that it gives the astrological interpretation and this gives historians an insight into the times. As stated previously, the Song and Jin were not on the best of terms, and this would later descend into military conflict. The account is clearly written from the Song perspective as the record refers to the Jin as 'slaves'. From the almost identical parallels with events 'to come' it seems that the record was written after the observation and well after the events it

[49] Translation taken from Green & Stephenson (2002)

claims to predict. Whether this was to enhance the reputation of the astronomers at the time by recording such an accurate prediction is speculation though – however the prediction does seem a little perfect! Note that the guest star was said to represent an ambassador from the Jin visiting at the time with the asterism it appeared in (*Chuanse*) representing his lodging.

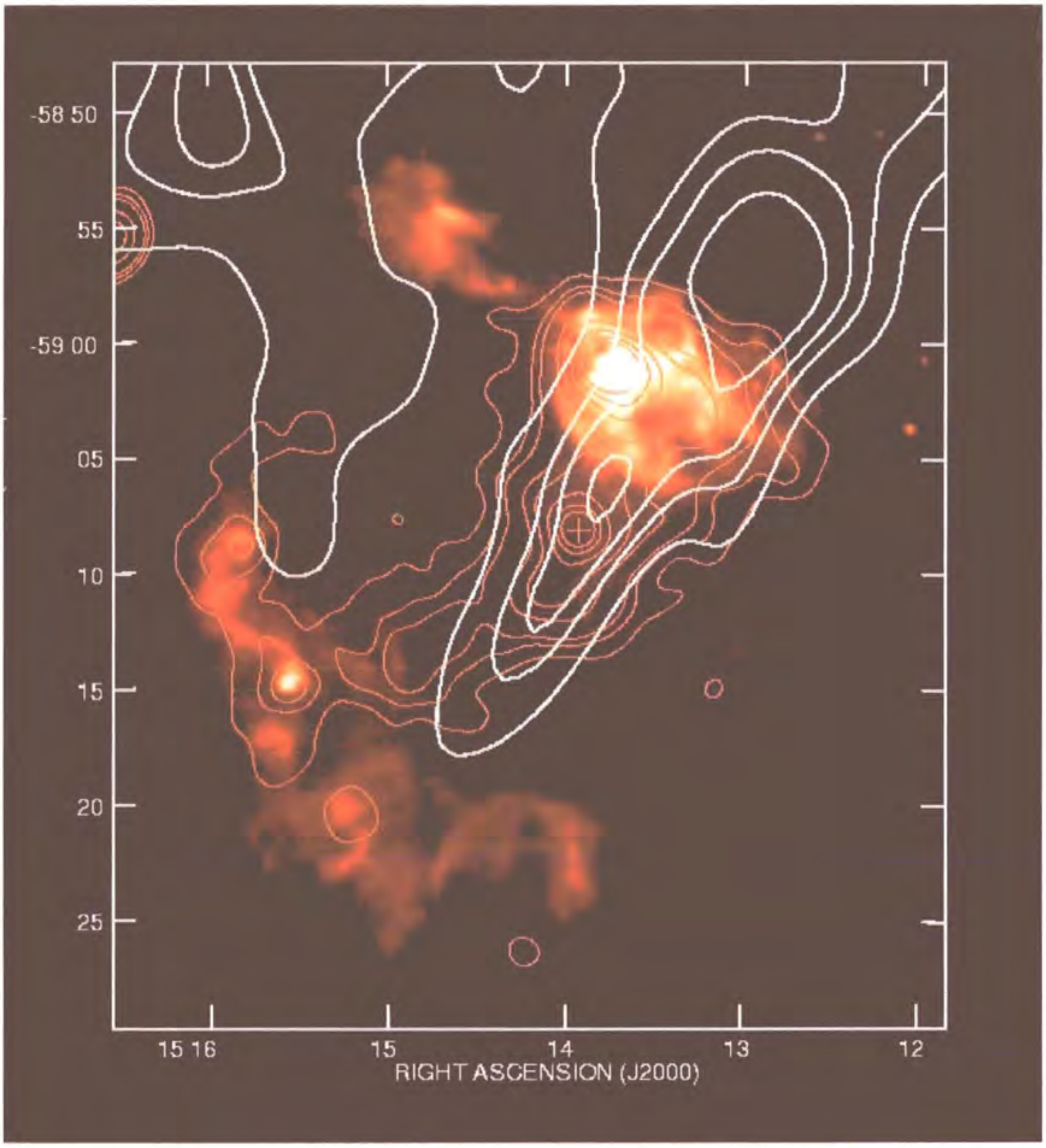
The record does give useful information about the location of the supernova, although accurate positional information is not strictly necessary given the lack of suitable supernova remnants in the area of Cassiopeia. A less detailed record is also mentioned in the *Songshi*:

> "Chunxi reign period, eighth year, 6th month, day *jisi*. A guest star appeared in *Kui* lunar lodge and invading the stars of *Chuanshe* until the following year, first month, day *guiyou*, a total of 185 days. Only then was it extinguished."

A record of similar length was also recorded by the Jin, the only difference being the length of visibility, at 156 days and a vague reference to the position of the star. A fuller analysis of these records is presented in Green & Stephenson (2002).

As with the similarly well-documented and researched supernovae of 1006, 1054, 1572 and 1608, there is no real doubt that the remnant 3C58 is the remnant of SN1181 given the lack of suitably aged remnants in the area given by the record in the *Wenxian Tongkao*.

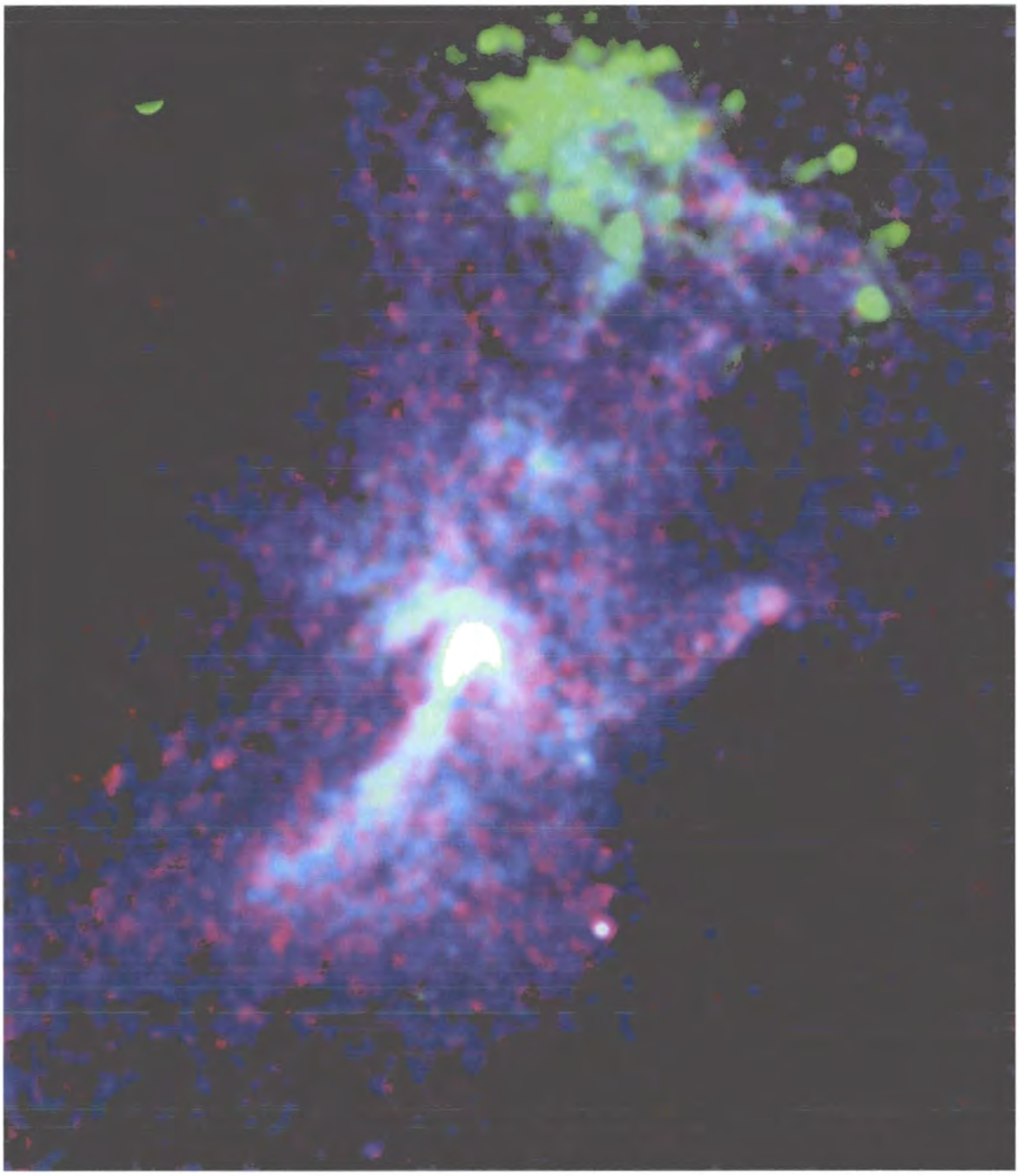
Plate 1



The SNR G320.4-1.2 and its surrounding medium (from Dubner et al. 2002, Astronomical Journal 123, 337). The image combines the SNR in radio (orange), the emission in X-rays (brown contours) and neutral hydrogen distribution (white contours)

(NASA)

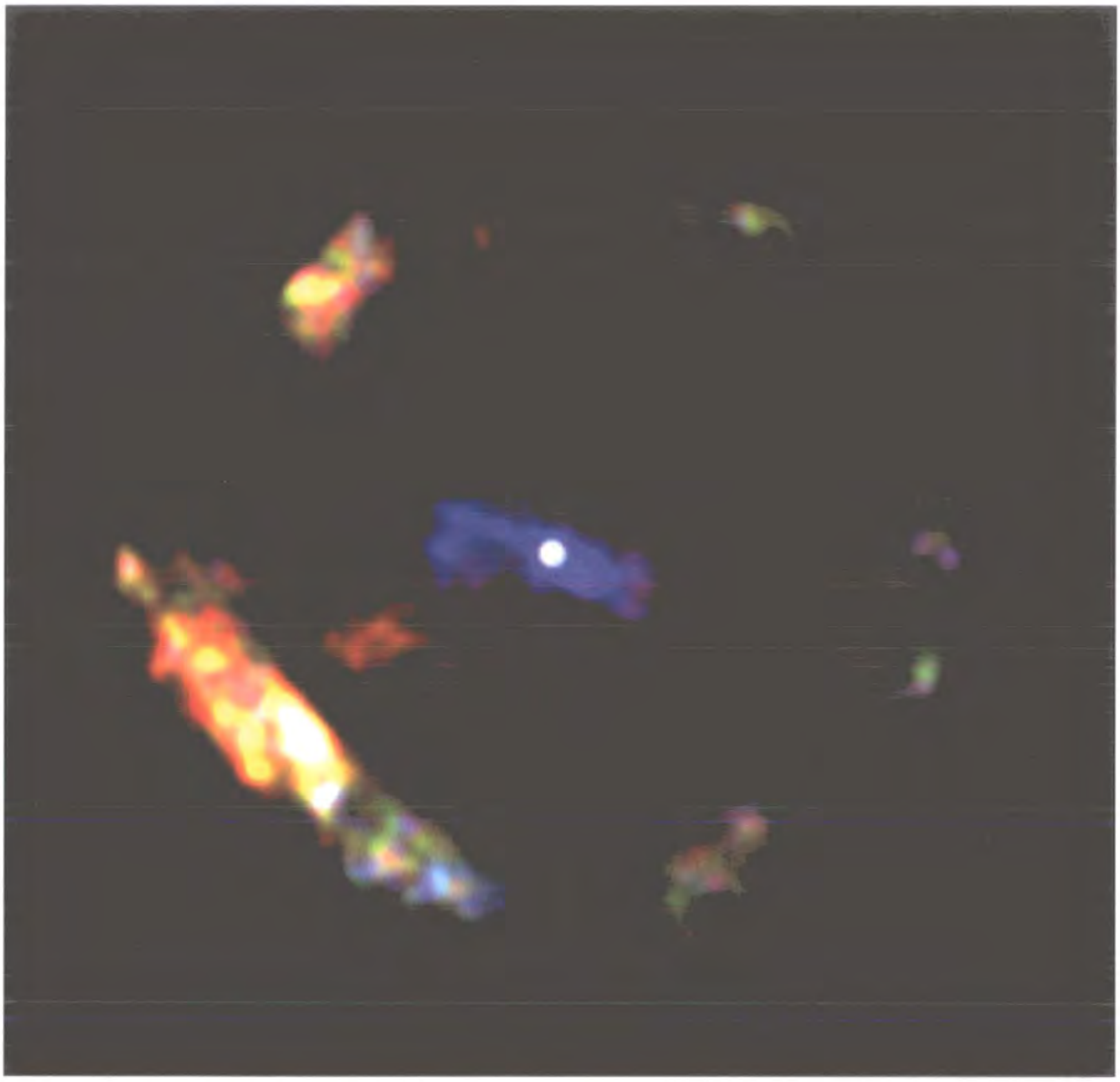
Plate 2



A Chandra X-ray image of the region surrounding PSR1509-58. The pulsar is associated with the remnant called G320.4-1.2. The pulsar is visible as a bright white source at the centre of the image. A number of x-ray plasmas surround the star and a thin jet of particles is being ejected from the pulsar s south pole, extending for 20 light years.

(*NASA/MIT*)

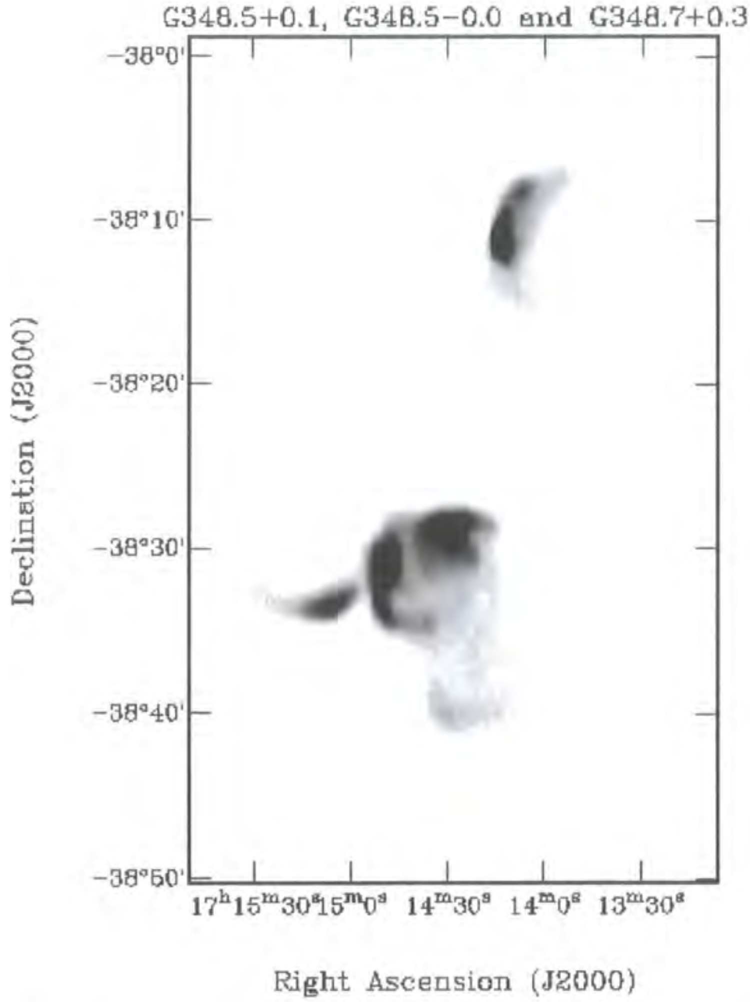
Plate 3



A Chandra image of G11.2 0.3 using the Advanced CCD Imaging Spectrometer. Note the pulsar at the centre of the remnant.

(*NASA/McGill/Kaspi et al.*)

Plate 4

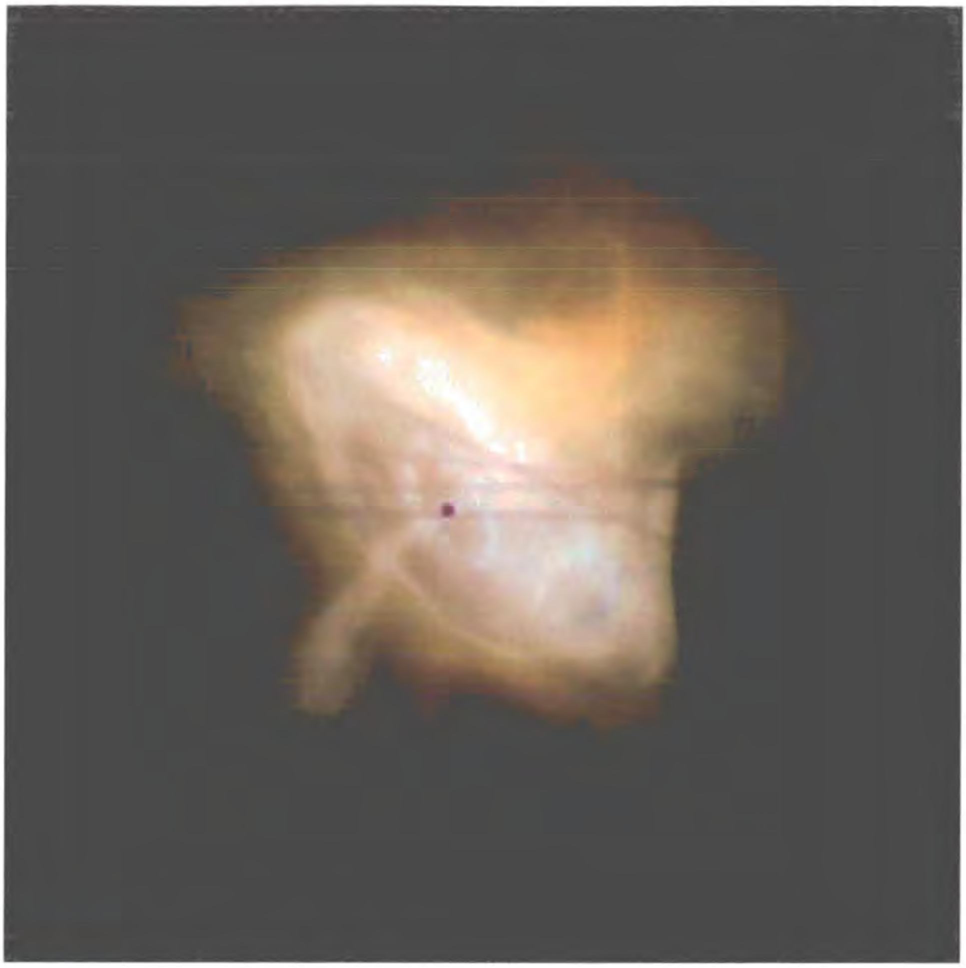


MOST (Molonglo Observatory Synthesis Telescope) image of remnants G348+0.1 (CTB37A), G348.5-0.0 and G348.7+0.3 (CTB37B)

(*J.B.Z. Whiteoak & A.J. Green, A&AS,* ***118****, 329*)

'The MOST is operated by the University of Sydney with support from the Australian Research Council and the Science Foundation for Physics within the University of Sydney.'

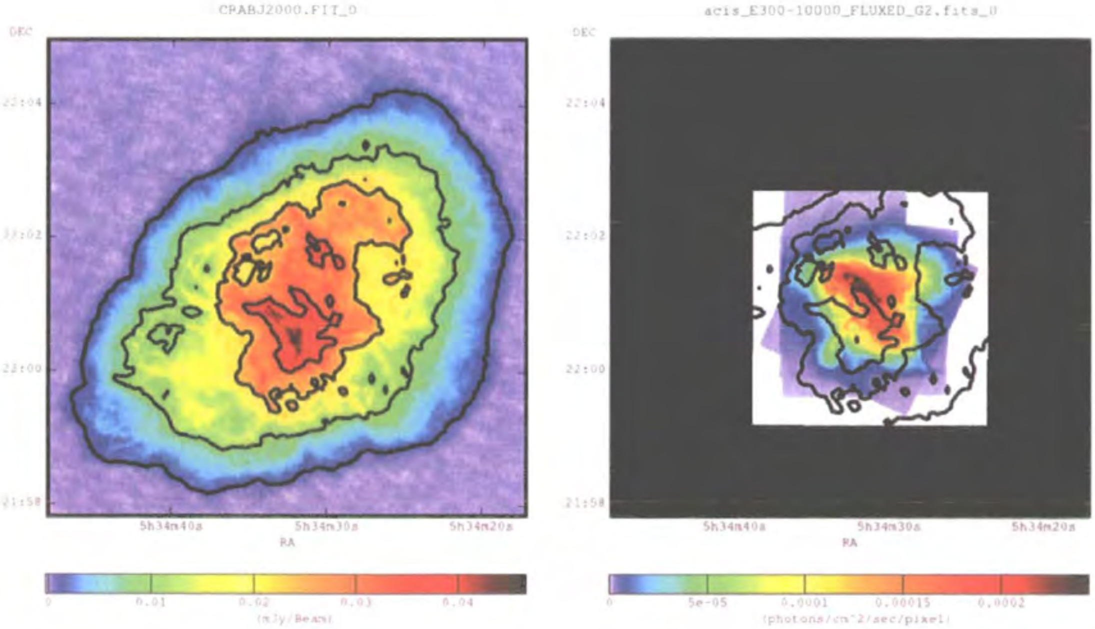
Plate 5



True colour image of the Crab Nebula.

(NASA/MIT)

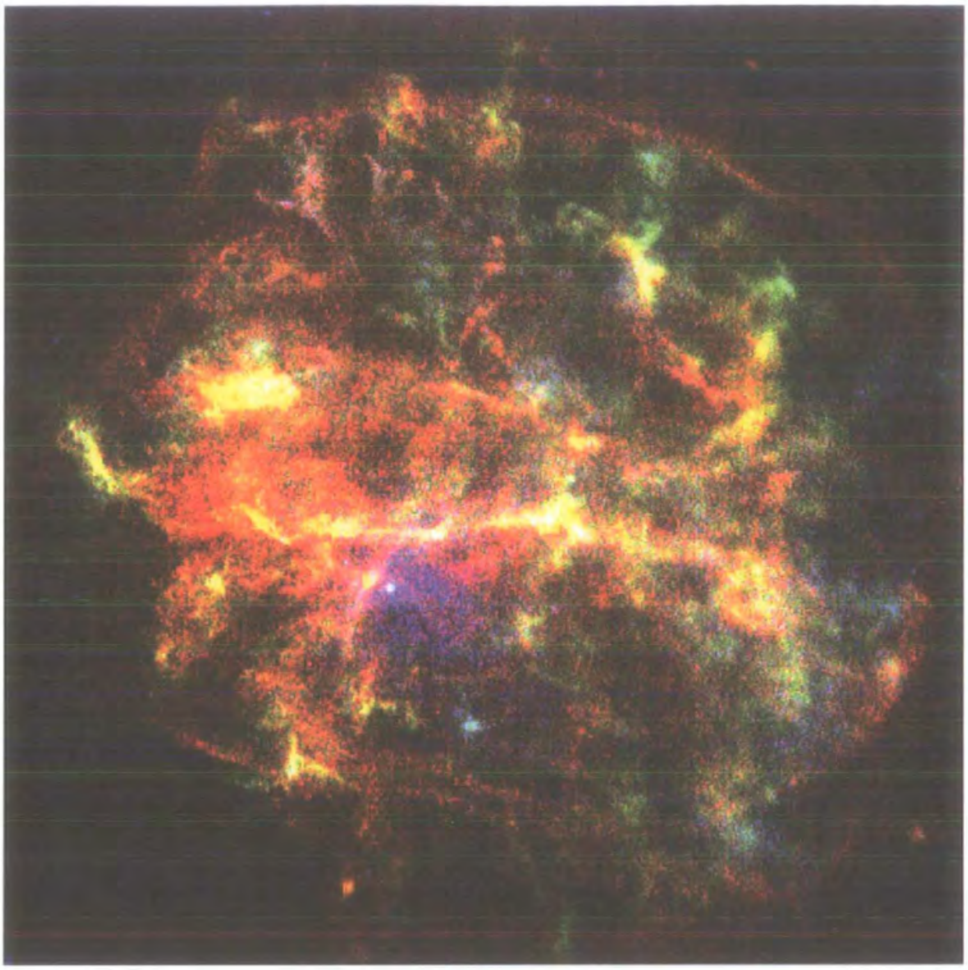
Plate 6



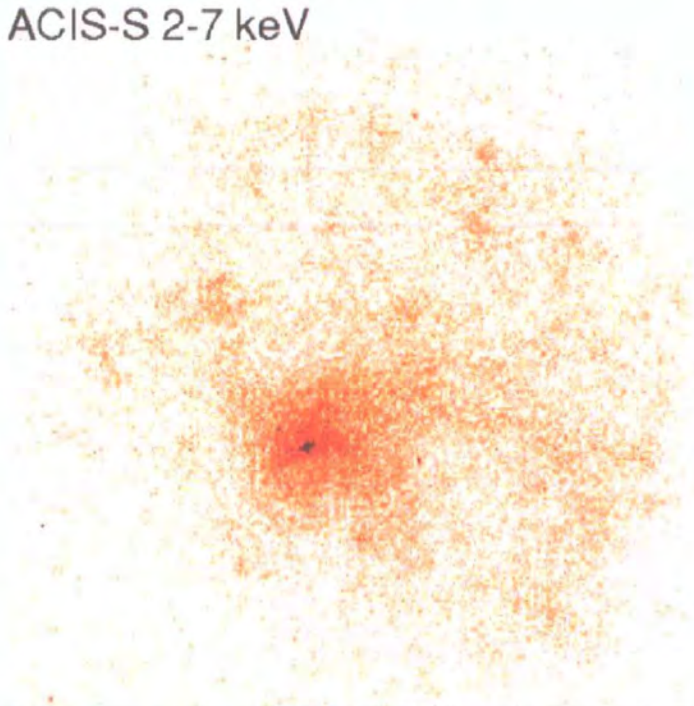
Radio image of the Crab Nebula (left) and Chandra x-ray image with radio contour lines.

(Bietenholz et al. 2001, ApJ, 560, 254)

Plate 7

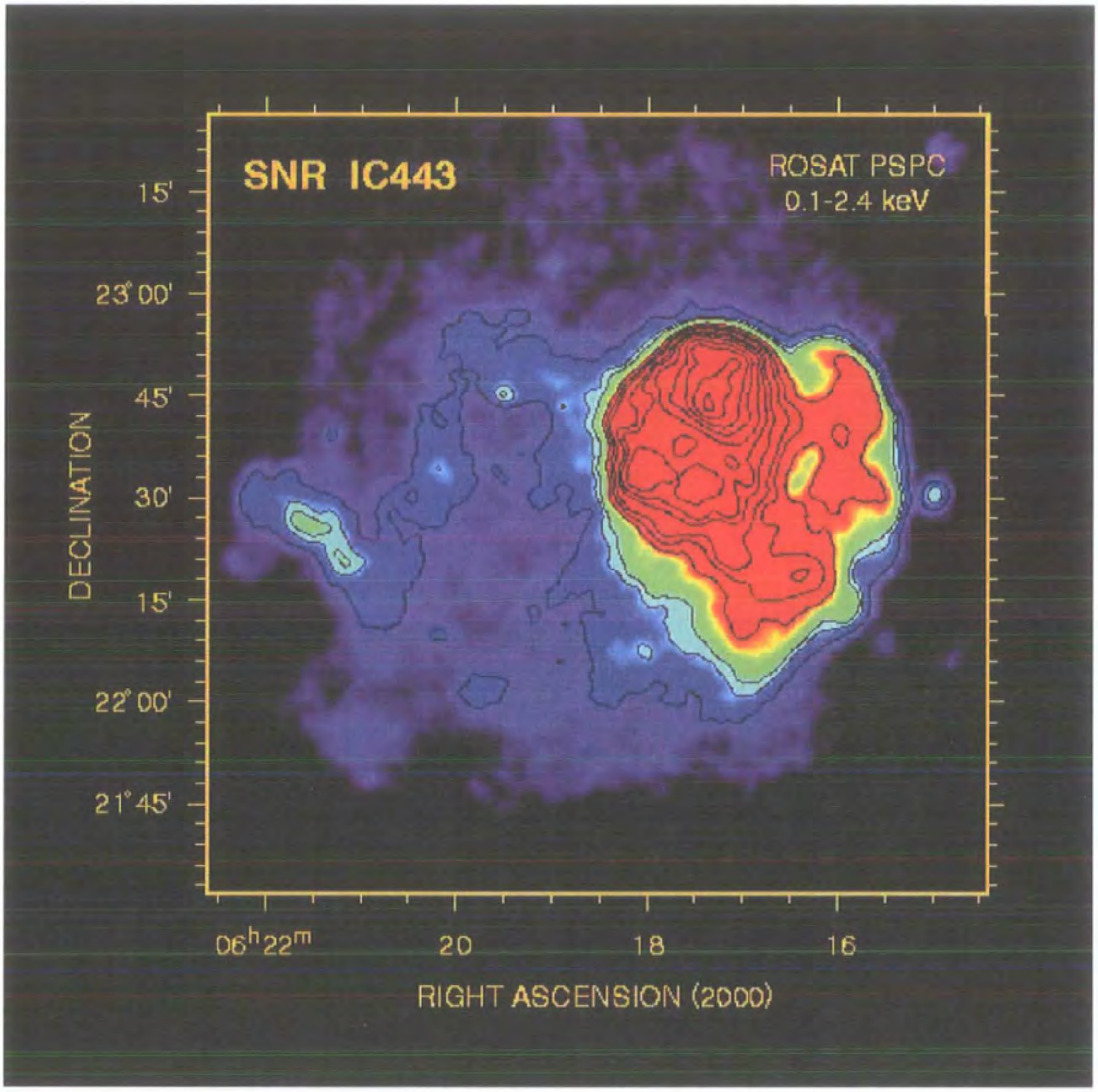


A Chandra true-colour image of the oxygen-rich remnant G292.0+1.8, associated with a supernova some 1600 years ago. A pulsar is thought to be at the centre of the remnant, shown in the image below.



(*NASA/CXC/Rutgers/Hughes et.al*)

Plate 8

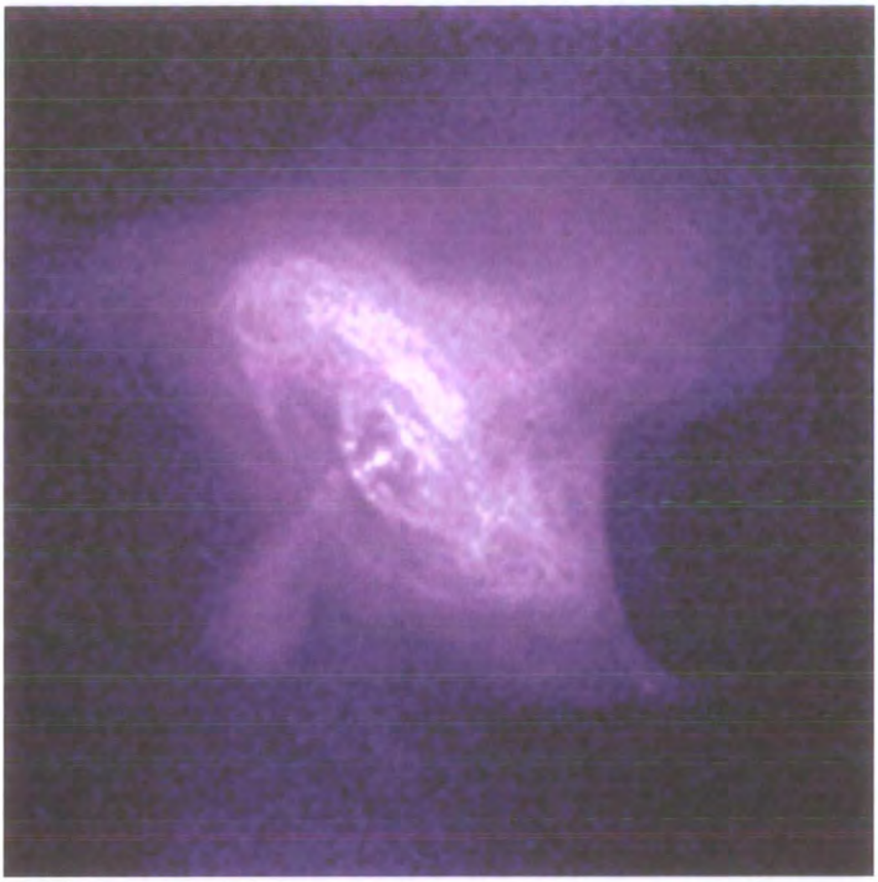


An x-ray image of IC443 observations using ROSAT. The colour is a measure of the x-ray intensity and on the right hand side of the image is the remnant G189.1+3.3.

(*Max Planck Institute*)

Plate 9

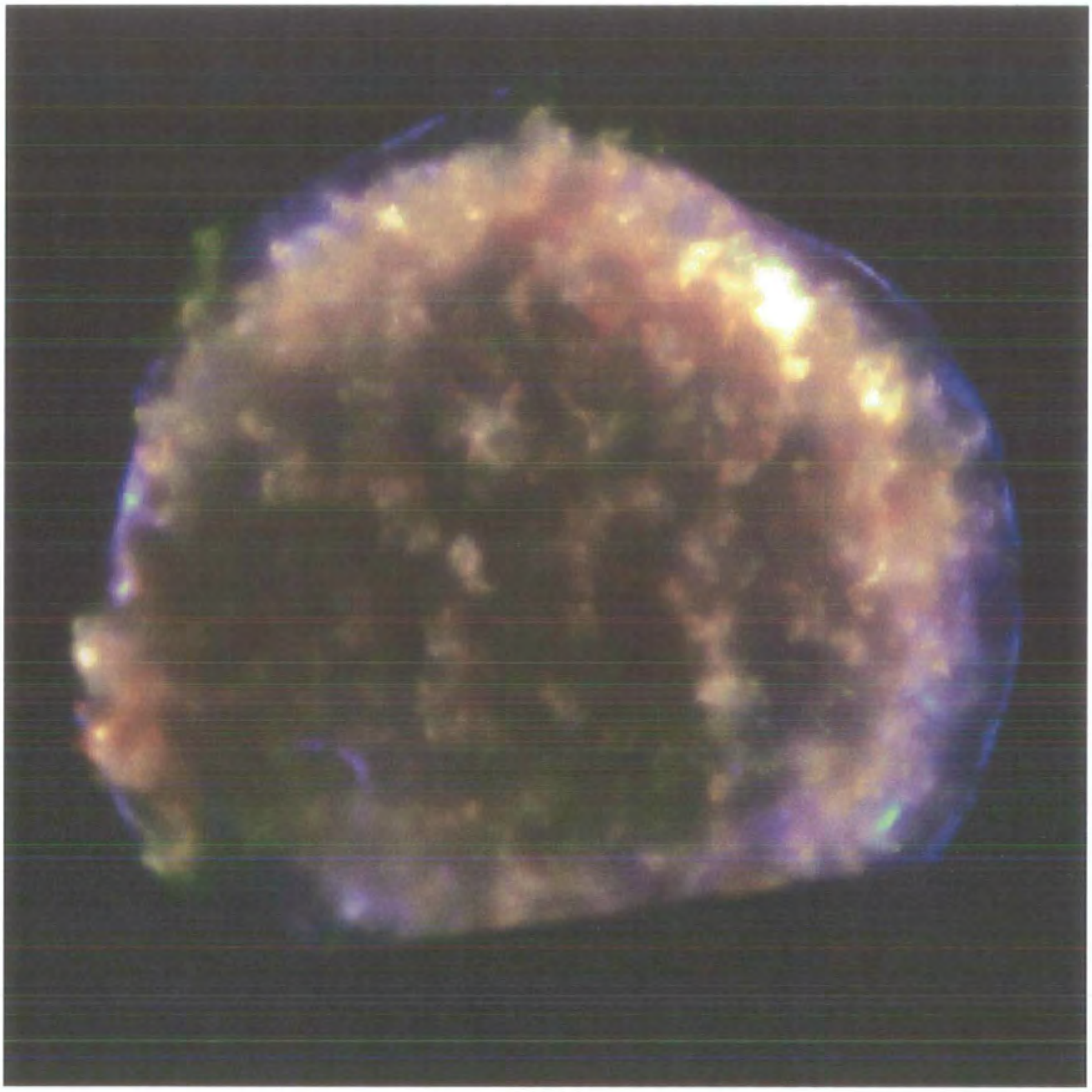
Images of the Crab Nebula, 6000 light-years from Earth and with a rapidly spinning pulsar at its centre. Images in x-ray from Chandra (top) and optical from the Palomar Observatory.



(*NASA/CXC/SAO*)

(*Palomar Obs.*)

Plate 10

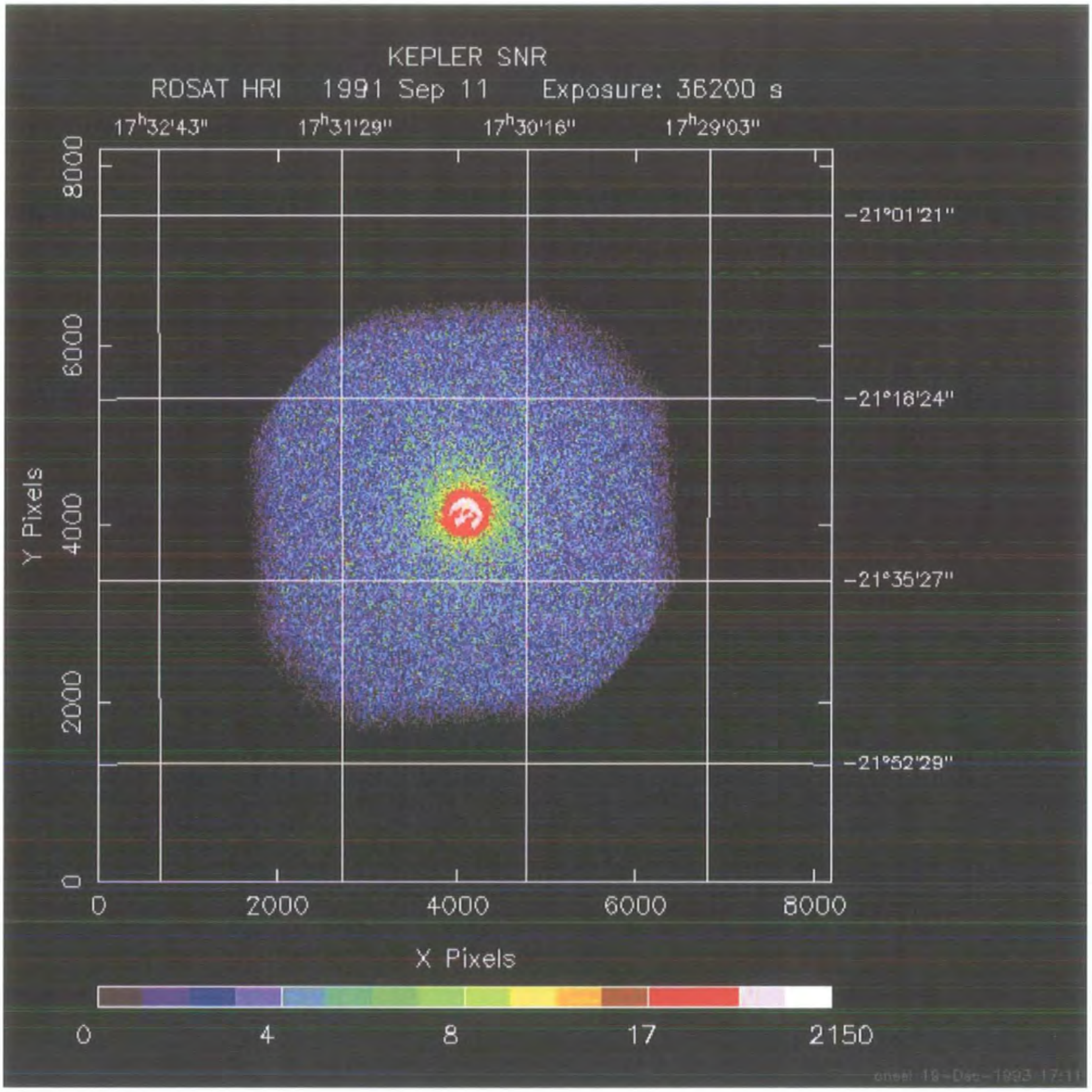


An x-ray Chandra observation of the remnant of Tycho s supernova. Note the distribution of matter in clumps as opposed to the knotty distribution of matter in Cas A.

(*NASA/CXC/SAO*)

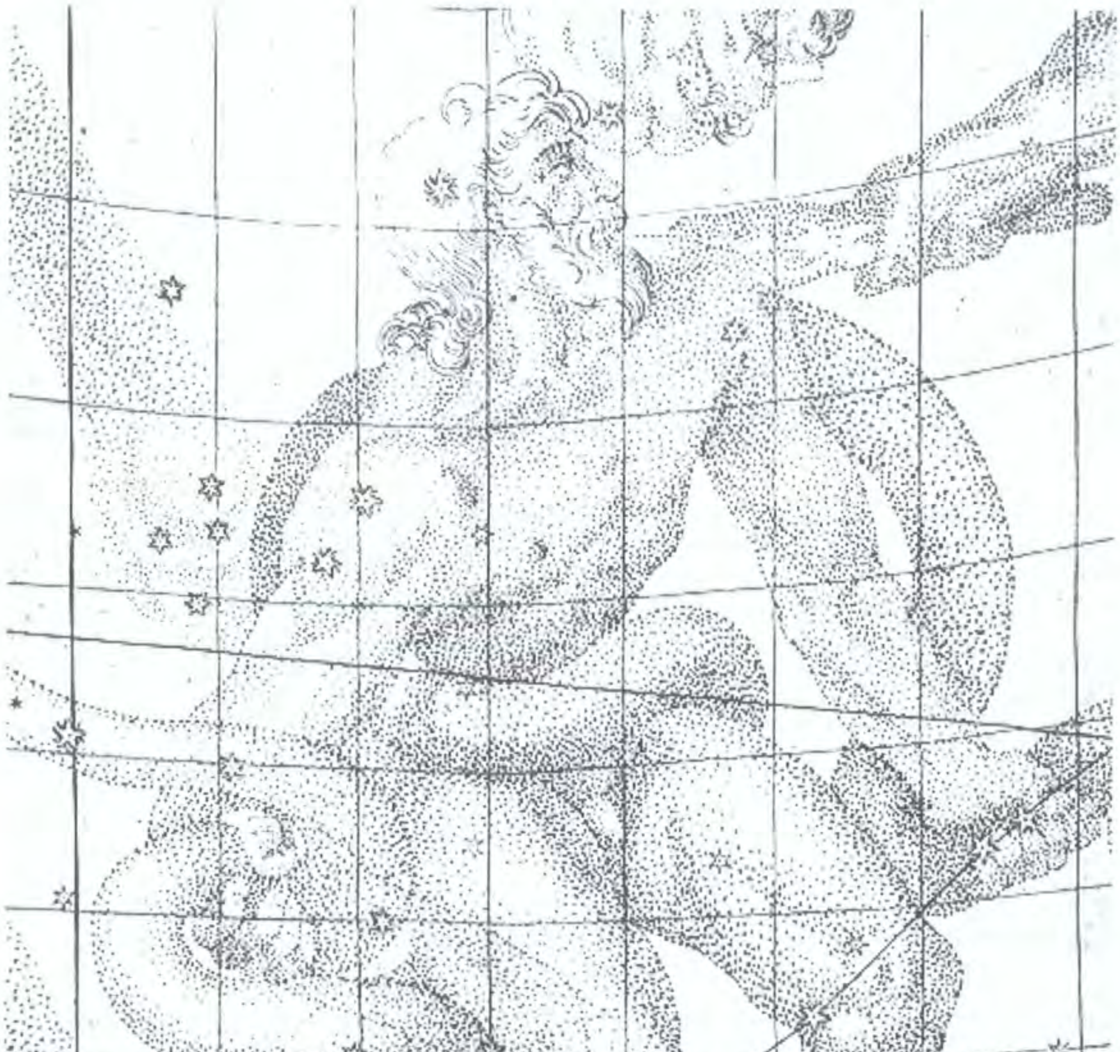
Plate 11

ROSAT x-ray image of the remnant of Kepler s Supernova. The remnant is unspectacular in the optical, but more detail can be seen in the x-ray region.



(NASA)

Plate 12



Kepler s drawing of the locations of the new star (at the heel of Ophiuchus). It appears in Kepler s work *De Stella Nova in Pede Serpentarii* (1604).

(*Linda Hall Library*)

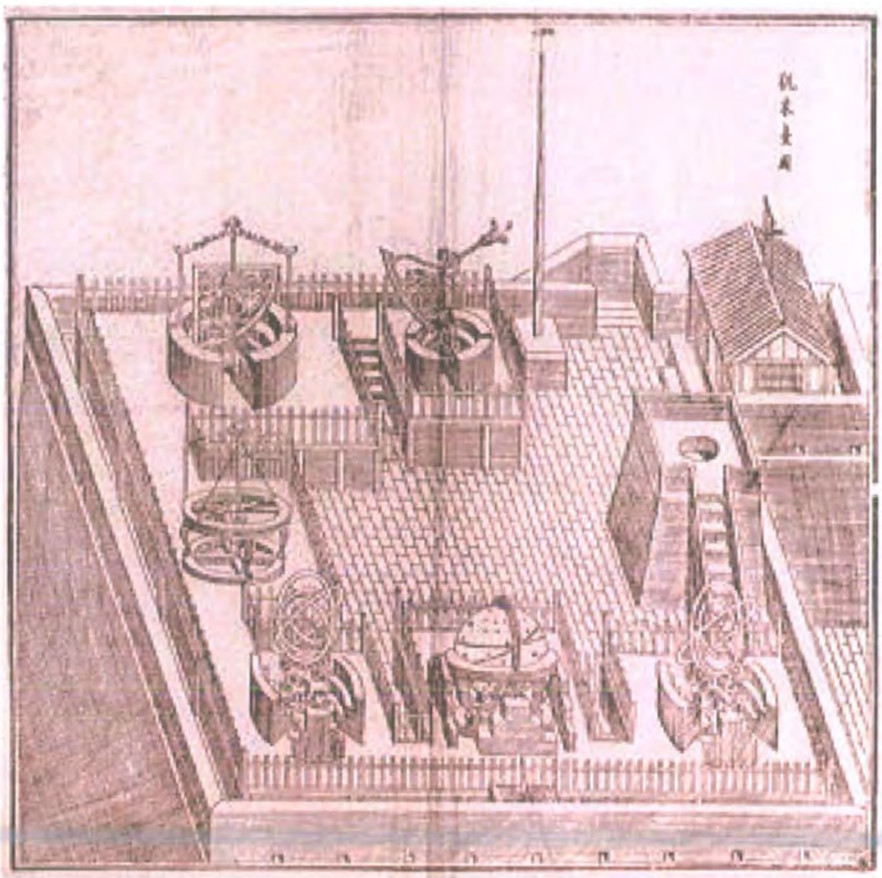
Plate 13

The Ecliptic Armillary Sphere at Beijing Observatory.

Plate 14

Chinese astronomers observing the Summer Solstice.

Plate 15



Astronomical instruments in the Imperial Observatory in Beijing made by the Jesuit missionary Ferdinand Verbiest (1670)

5 THE SUPERNOVAE OF 1006, 1054, 1572, 1604 AND THE SUPERNOVA OF THE LATE-SEVENTEENTH CENTURY

The supernova of AD1006, 1054, 1572 and 1604 are well documented and researched and there is little doubt that the remnants associated with the events are the results of their respective supernovae. For this reason, the remnants and associated records will be described and discussed briefly for completeness of this discussion about historical supernovae.

5.1 SN1006

As well as being observed by the Chinese, the supernova of 1006 was observed in many civilisations throughout the world, including those in Japan, Arabia, Korea and even mediaeval Europe. The supernova was marked by its extreme brilliance, and although reports may be exaggerated, the supernova was said to rival a quarter-moon in brightness and may have lasted up to three years. The supernova was first sighted between April 28th and May 3rd 1006 depending on the record and most likely on May 1st in East Asia.

The record of the supernova can be found in many Chinese sources and these are the most comprehensive of any civilisation as could be expected. It is thought that the records from various Chinese sources are all derived from observations made at the then Song capital of Bian. A record from the *Songshi* (*Tianwen zhi*, chap.26) reads as follows:

> "Emperor Zhenzong of Song, 3rd year of the Jingde reign period, 4th month, day *wuyin*. A *zhoubo* star emerged south of *Di*, one *du* west of *Qiguan*. It was shaped like half a Moon and had horned rays. It shone so brightly that one could see things in detail. It passed through the east of *Kulou*. In the 8th month

> it followed the celestial sphere and entered the horizon. In the 11th month it was again seen in *Di*. From this time on, during the 11th month it was frequently seen in the east during the hour of *chen* and in the 8th month it entered the horizon in the southwest."

An almost identical record is found in the *Wenxian Tongkao*. Other records of the guest star can be found in Appendix 2. The star is referred to as *zhoubo*, or 'Earl of Zhou'. The sighting of a *zhoubo* star was said to "bring[s] prosperity to the state where it visits"[50] and was named after one of the founders of the Zhou Dynasty. Although the record contains apparent references to motion, these are interpreted as otherwise and depend on the translation of *li*; in this case used in the context of 'passing through time'.[51]

An astrological interpretation of the supernova is recorded in the *Qingli guozhao huiyao*[52] (1044).

> "When the *zhoubo* star appeared, Heaven revealed a special sign of saintly virtue [on the Emperor]. The official historians were asked to follow up and record the matter. Civil and military officials congratulated the Emperor. When the star first appeared, people who were versed in astrology said many times that it was auspicious. Although there were grounds for believing this, the Emperor did not accept it. Not until the Superintendent Astronomer and the Hanlin academicians repeatedly reported it did the Emperor listen to them. The officials congratulated the Emperor."

This record indicates that the people and astronomers were keen to appease the Emperor, and this was reflective of the times. The Song had been previously involved in war with the Khitans, and although a settlement was eventually reached, this involved the Song giving the Khitans a considerable amount of silk and silver every year. Hence the court officials were

[50] Astrological interpretation from the *Astronomical Treatise of the History of the Jin Dynasty*, Chapter 26. However, the *Astronomical Treatise of the History of the Sui Dynasty* interprets a *zhoubo* as bringing "military action, death and countrywide famine".
[51] See Green & Stephenson (2002), p.153.
[52] This was concerned with political matters during part of the Song dynasty from 960AD to 1043.

particularly aware of the effect a 'bad omen' could have, and also aware that the Emperor believed strongly in astrology and hence a 'good omen' and repeated congratulation could help their personal goals.

From records from Europe and Arabia, we can narrow our search for a remnant somewhat. Accounts from the *Songshi* give a position near to the constellation of Lupus, and Japanese records also give positions relative to the nearest star. In the immediate region (14h30 to 13h00 right ascension and –45° to –30° declination) there are only two supernova remnants, G327.6+14.6 and the Lupus Loop with no other remnants within ten degrees. The high galactic altitude of the Lupus region aids our search given the near absence of supernova remnants.

Immediately, the Lupus Loop can be discounted given its high degree of evolution and size. However, this leaves G327.6+14.6, and given the repeated recording of the extreme brilliance of the supernova, this leaves some uncertainty as the supernova would have to be extremely close (~1kpc) and almost certainly of Type Ia. The remnant is of suitable type (shell) to be associate with a Ia explosion and within 1.6 to 3.0 kpc. Although with these values it is unlikely the supernova would rival the moon for brilliance, these facets of the records can be attributed to exaggeration, and given the lack of remnants in the area, it is certain that G327.6+14.6 is the remnant of SN1006.

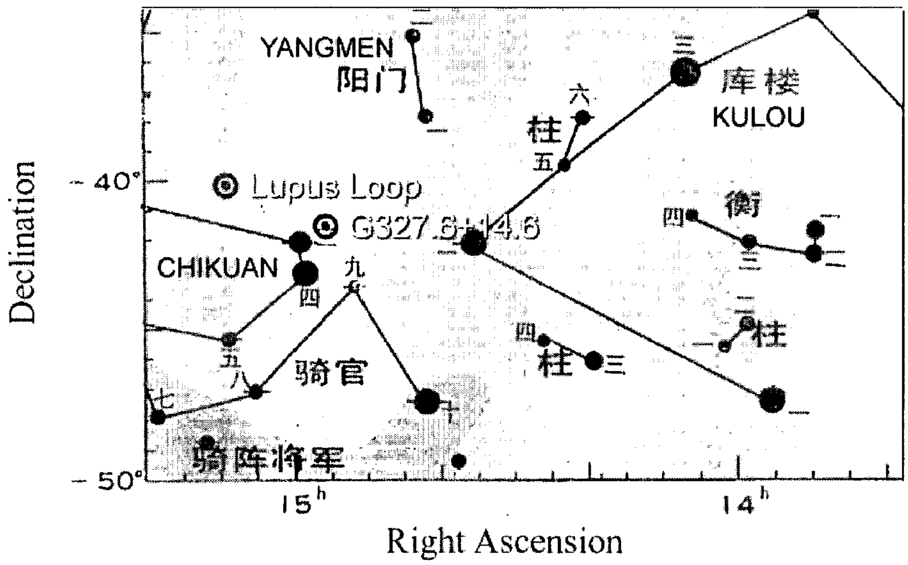


Figure 5.1 – *The Area Surrounding G327.6+14.6*

5.2 SN1054

Similarly to the supernova of 1006, the supernova of 1054 has also been well researched, and the resultant remnant, known as the Crab Nebula, is used as a comparison for other SNRs. There is little debate surrounding the identity of the possible remnant given the lack of suitable candidates in the vicinity of the observations.

5.2.1 The Crab Nebula

The remnant of the supernova of 1054 is of filled-centre type and contains a pulsar at its centre powering the remnant, with the nebula measured at 6 million light years across and expanding at a rate of 1400 kms^{-1}. It has been widely studied to its proximity to Earth and was the first identified x-ray source in 1963 and the nebula is bright in optical, radio and x-ray wavelengths. The proper motion and radial velocity give the distance to the remnant at 2 kpc.

Early research into the Crab Nebula was aided by a number of observations in the optical regime, with the discovery of the nebula (discounting the observations of ancient astronomers) being made by the amateur astronomer John Bevis in 1731, and was independently discovered by Messier when conducting observations of Halley's Comet (1758). Numerous observations were subsequently made by Herschel and Lord Ross amongst others, and it was Ross who named the nebula 'Crab' through its similarity in shape to a crab's claw.

Early analysis of the spectrum of the nebula, showed the nebula to be rich in oxygen, nitrogen and sulphur, in common with a planetary nebula. Present is thermal emission from ionised species (associated with the 'filaments' in the structure) and synchrotron emission from particles trapped within the magnetic field generated by the central pulsar, and it is the synchrotron emission that is associated with the diffuse regions of the nebula.

The age of the Crab Nebula is determined from the central pulsar, first discovered by Staelin & Reifenstein[53] (1968) although the presence of such an object had been previously proposed. The pulsar, of period 33ms, has a characteristic age of ~1250 years; this age being in agreement with a supernova in 1054 and the presence of this pulsar indicates that the progenitor star was massive. Further evidence corroborating the age of the pulsar includes the presence of a jet of particles, presumably due to the presence of the pulsar and studies have shown that the jet is of similar age to the pulsar from its rate of radial expansion[54].

[53] D.H. Staelin & E.C. Reifenstein, *Pulsating radio sources near the Crab Nebula* (1968), Science, 162, 1481

[54] Fesen & Staker, *The structure and motion of the Crab nebula jet* (1993) MNRAS, 263, 69

5.2.2 Chinese Records

A record from the *Songshi* reads as follows:

> "Emperor Renzong of Son, 1st year of the Zhihe reign period, day *jichou*. A guest star emerged several *cun* southeast of *Tianguan*. After more than a year it gradually disappeared."

Tianguan is a star believed to be ξ-Tau. This translation is almost identical to a record in the *Wenxian Tongkao*, and most of the observations by the Song astronomers appear to be the source for the majority of Southern Chinese observations. The term *cun* roughly translates as 'inches'. A detailed discussion of the position of the guest star with relation to *Tianguan*, including verification of the term *cun*, is provided in Green & Stephenson. Also discussed is the identity of *Tianguan*; namely its association with ξ-Tau. The long period of observation rules out either a comet or nova, especially with no allusion of movement.

A record from the *Song huiyao jigao* (chap.52) contains some interesting information concerning its brightness and hence distance constraints.

> "Emperor Renzong of Song, 1st year of the Jiayou reign period, 3rd month. The Director of the Astronomical Bureau said. 'The guest star disappeared; this is an omen that a guest will leave. Initially, in the 5th month of the 1st year of the Zhihe reign period, [the guest star] appeared at dawn in the east guarding *Tianguan*. During daylight it appeared like Venus, with horned rays radiating in all directions. It had a reddish white colour and lasted for a total of 23 days."

The visibility during daylight implies a minimum apparent magnitude of –4, this being equivalent to the brightness of Venus. This further places a constraint on the distance of the supernova, and means the supernova must have been within 3 kpc. This of course does not take into account any extraordinarily energetic explosion, and assumes a normal supernova event. The proper motion and radial velocity of the Crab Nebula give a distance of 2 kpc – within the 3 kpc constraint.

A problem with the identification of the Crab Nebula with the guest star sighted near to ξ-Tau is the fact that the Crab Nebula is situated to the northwest of ξ-Tau, rather than to the southeast as recorded in the primary sources (including the *Wenxian Tongkao* and *Songshi*). Breen & McCarthy (1995) and Green & Stephenson (2002) offer explanations centred on the use of the word 'guarded' in some records, and suggest that a mistake in the recording of the original Chinese record was to blame for a position southeast being recorded.

Despite any problems with translations, positions and similar, due to the lack of remnants in the vicinity and records associating the Crab Nebula with an alternative guest star sighting, there can be little doubt that the Crab remnant is that of SN1054.

5.3 SN1572

Of all the historical supernovae, SN1572 is perhaps the best recorded and leaves no doubt about the identity of the remnant. This is due largely to the work of the eminent astronomer Tycho Brahe, who made detailed observations of the supernovae including a complete light curve for the event. Measurements taken in Europe isolate G120.1+1.4 (3C10) as the likely candidate for the remnant of SN1572.

5.3.1 European Observations of SN1572

Although the observations of Brahe are beyond the remit of this discussion, a brief description of them would be useful for completeness. This is mainly due to the importance of Brahe's observations in identifying a remnant – although the supernova was recorded as expected by astronomers in China, due to the lack of detail as seen in Brahe's records oriental records are largely an aside. The supernova was also recorded by Digges and these observations lack the systematic errors present throughout Brahe's observations, although Brahe retains much of the credit for initially observing the supernova. The observations are recorded in Brahe's *Astronomiae Instaurate Progymnasmata*[55] (1602).

Brahe observed the supernova a while after others, notably the Spanish mathematician Mugnoz and Francesco Maurolyco, a Sicilian abbot, also a mathematician. Their records show that both sighted the supernova on 6th November 1572, with Brahe first observing the supernova on November 11th. His account of the first observation of the supernova reads[56]:

> "...Behold, directly overhead, a certain strange star was seen, flashing its light with a radiant gleam and it struck my eyes. Amazed, and as if astonished and stupefied, I stood still, gazing for a certain length of time with my eyes fixed intently on it and noticing that same star placed close to the stars which antiquity attributed to Cassiopeia."

Brahe immediately conducted measurements using basic tools (a half-sextant) noting the physical characteristics of the new star. The light curve recorded by Brahe clearly shows the guest star to be a supernova, although the measurements are not accurate enough to determine a specific type. Brahe noted the colour to be initially white, then reddish (by comparison

[55] Astronomiae Instaurate Progymnasmata – *"Essays on the New Astronomy"*
[56] Translation taken from Green & Stephenson (2002).

with Betelgeuse and Aldebaran), before returning to white. Note that Chinese astronomers recorded the colour to be reddish-yellow. None of the original observations remain, and his finalised measurements are recorded in chapter 4 of the *Astronomiae Instaurate Progymnasmata.* Using the angular separation of the supernova from the stars in Cassiopeia, its distance from Polaris, and assuming his latitude to be 55°58' and the supernova's altitude at lower culmination to be 27°45', he estimated the declination of the supernova to be 61°47'. No right ascension measurement remains. However, most of Brahe's measurements used in determining the position of the nine stars in Cassiopeia (and hence the declination of the supernova) were systematically high with a mean error of two arcminutes. Clark & Stephenson (1977) determined the corrected position of the supernova to be RA 0h24m51s, Dec +64°9'3". Note that Digges measurements did not contain the systematic errors as seen in Brahe's observations.

5.3.2 Chinese Observations of SN1572

In comparison to the observations of Brahe and Digges, the Chinese records are little more than incidental. Records exist from the *Shenzong Shilu*[57] and also from chapter 25 of the *Mingshi* (astronomical treatise). The full record from the Shenzong Shilu is long and can be found in Appendix 3 – the record is not only concerned with the observation of the guest star, but also with the astrological interpretation and reaction to the appearance of the guest star.[58]. The section of the record concerned with the actual observation is given below:

[57] Shenzong Shilu – "*Veritable Records of the Reign of Ming Emperor Shenzong*"

[58] Note that Emperor Muzong died in the July of 1572, and Emperor Shenzong had ascended to the throne at the time of the appearance of the guest star. Although Shenzong was Emperor at the time of the supernova, Chinese tradition dictated that a reign period lasted until the end of the calendar year and hence Muzong's name is written in the record.

> "Longqing reign period, sixth year, 10^{th} lunar month, day *xinwei*... Previously, in the 10^{th} lunar month, 3^{rd} day *bingchen* at night a guest star was seen at the northeast direction. It was like a crossbow pellet. It appeared beside *Gedao* in the degrees of *Dongbi* lunar lodge. It gradually had small pointed rays and it was bright. On the 19^{th} day *renshen*, at night this star was reddish-yellow in colour. It was as large as a cup and its light rays were in the four directions. The standard interpretations say: 'This is a bushy star. It is sometimes seen before sunset'. The standard interpretations (additionally) say: 'It is also seen in the day'."

From the ramifications of the guest star sighting (see Appendix 3), we see that the guest star is taken as a portent of bad tidings and the Emperor orders his officials to undergo "rigorous self-examination" in order that they may eliminate the threat of the guest star. This shows what political and spiritual importance the Chinese placed on such cosmic events, and from contemporaneous European records, many European astronomers also saw the appearance of the star as a sign of bad things to come.

The records in the *Mingshi* are of no real importance and are mentioned only briefly by the chronicler.

> "There are also some [stars] which did not exist in ancient times but which exist now. Beside *Cexing*[59] there is a guest star. During the first year of the Wanli reign period this newly appeared. At first it was large, now it is small."

5.3.3 The Remnant G120.1+1.4

The remnant associated with the supernova of 1572 is well studied, primarily because of its definite time of formation. First identified in radio by Hanbury Brown & Hazard[60] (1952), it is a shell type remnant that has almost entered the Sedov-Taylor stage, and HI absorption measurements

[59] *Cexing* was a star in Cassiopeia.
[60] R. Hanbury Brown & C. Hazard, (1952), Nature, 170, 634

place the remnant at 2-5kpc, whilst shock velocity measurements place the remnant at 2.4kpc. An apparent neutron star and strong radio source at the centre of the remnant has been shown not to be a neutron star[61] and is instead thought to be extragalactic. There is no astrophysical evidence to suggest that the remnant is not that of SN1572.

5.4 SN 1604

Kepler observed another supernova just 32 years after the supernova of 1572, and hence the supernova is known as Kepler's Supernova. Kepler, a student of Brahe, who had died three years previously, kept the same meticulous observations as Brahe had. The supernova was again seen in East Asia, and Chinese astronomers kept more detailed observations – the supernova was again during the reign of Emperor Shenzong, who had only been aged ten at the time of the last supernova. Again, although the supernova was not as bright as SN1572, the light curve information recorded by Kepler clearly shows a supernova event, although no type can be determined from this alone.

The supernova was first sighted in Europe on October 9th 1604 and observed in China a day later. The Korean records for this supernova are uncharacteristically complete and have aided historical astronomers in locating a possible remnant, as opposed to the Chinese records from SN1572.

5.4.1 Johannes Kepler's Observations of SN1604

[61] D.A Green & S.F. Gull, *Neutral hydrogen observations towards the compact radio source 0022 + 6352 in Tycho's SNR* (1987), MNRAS, 224, 1055

Kepler, based in Prague at the time, first observed the star on October 17th, although the star was first seen in Europe by Fabricius and Altobelli, both Italians, on October 9th. Kepler's account of the supernova is recorded in *De Stella Nova in Pede Serpentarii*[62] (1606) - Baade[63] (1943) conducted comprehensive research into this and other European records surrounding the supernova of 1604. As Brahe did 32 years earlier, Kepler measured the angular separation between the planets Mars, Jupiter and Saturn and six other bright stars[64] using a sextant, although low altitude made observations problematic. From his measurements he found the supernova to be at RA $17^h7^m8^s$ and Dec. –21°01', which is virtually that observed by modern astronomers.

Kepler also made observations of the brightness of the supernova by comparison against the planets and nearby stars, and from his and other European observations, Baade concluded the maximum was on October 17th. Kepler continued to make observations of its brightness until it disappeared almost a year later. Although Baade and Clark & Stephenson (1977), using the original European and Korean records constructed a light curve and concluded it to be Type I, this cannot be substantiated as the curve is not distinct enough to make a final conclusion between Type Ia and Type II-L curves.

5.4.2 The Remnant G4.5+6.8 (3C358)

This was first associated with SN1604 by Baade using the 100-inch Mt. Wilson telescope (1941), and subsequently identified in the radio region in

[62] De Stella Nova in Pede Serpentarii – "*Concerning the New Star on the Right Foot of the Serpent Holder*". The constellation of Serpentarius, or the Serpent Holder, is usually known as Ophiuchus.
[63] W. Baade, *Nova Ophiuchi of 1604 AS a Supernova* (1943), ApJ, 96, 188
[64] The six stars were σ-Sgr, η-Oph, α-Oph, ξ-Oph, α–Aql and Antares.

1957[65]. It is a shell-type remnant and HI absorption measurements place the remnant at 4.8-6.4kpc, and this distance accounts for its faintness (as well as the low position in the sky). There is no central neutron star in the remnant. The spectrum is in agreement with Type Ia explosion, although it is also in agreement with a Type-II explosion of a massive star. However, the absence of a hard central component suggests that the supernova was indeed of Type Ia. Again, there is no astrophysical evidence to suggest that 3C358 is not the remnant of Kepler's supernova.

5.5 The Supernova of the Late-Seventeenth Century

There is a surprising lack of Chinese records concerned with a supernova in the late-seventeenth century. There is a young and nearby SNR in the constellation of Cassiopeia which has lead many to search for suitable records to match a supernova resulting in this remnant. This remnant, Cassiopeia A (Cas A, G111.7-2.1), is one of the brightest radio sources in the sky and was first observed towards the end of the 1940s.

Although there is much debate as to whether the Astronomer Royal of the time, John Flamsteed, observed the supernova, this is largely irrelevant to the corroboration of Chinese records with this supernova and as such is beyond the scope of this thesis.

It seems strange, given the meticulous records kept by oriental astronomers, that there are no 'proper' observations from the official astronomers of the time nor any records from local Chinese histories, and there is no hint of a mention of a new star in the Cas A region from 1600 to 1877. Chinese records have been extensively catalogued and translated both by Ho Peng Yoke (1970) and by the Beijing Observatory, and it must be assumed that

[65] J.E. Baldwin & D.O. Edge, *Radio emission from the remnants of the supernovae of 1572 and 1604* (1957), The Observatory, 77, 139

the relevant records, if they existed at all, must have been lost or destroyed. There are also no known records relating to Cassiopeia A from Korea or Japan from this time.

6 CONCLUSION

It is obvious that, given the infrequency of supernova events, historical supernovae are of importance to understanding stellar evolution, and in particular the evolution of supernova remnants. By associating known historical supernovae with observed remnants, we can not only shed light on the properties of these remnants but also use this information in our understanding of other remnants in general.

In this paper, various supernova remnants that have been suggested as suitable candidates have been compared against Chinese records to verify their suitability as historical supernova remnants. Largely, this has been for supernova before 1000AD, as the historical supernovae after this have been extensively researched and there is little doubt that the remnants suggested for these are not those of their respective supernova.

For the supernova of 185AD, two remnants have been suggested as possible, G315.4-2.3 and G320.4-1.2, based on their positions. G315.4-2.3 is the favoured remnant by myself and others, given that G320.4-1.2 appears to be at a greater distance than is needed for a supernova to be seen on Earth. G315.4-2.3 is also of suitable age and distance and is much more likely to be the remnant of SN185. Various arguments against the association of the record relating to SN185 with a supernova have also been considered and I am in agreement with others that these arguments are invalid.

The remnant G11.2-0.3 has been associated with a supernova in 386AD, and the major piece of evidence suggesting the youth of this remnant is the central pulsar. Since the pulsar would not likely be found at the centre if the remnant were old, this would suggest the remnant is young, and estimates show it to be around 2000 years old. The record from 386 seems to support the association of the remnant with the supernova, and although there was another record from 45BC which could be associated with a supernova and the same remnant, this is thought to be a nova sighting.

A supernova was observed in 393AD in the region of Scorpius and this was perhaps the most difficult to attribute a remnant to. Two remnants, CTB37A and CTB37B have already been suggested as the remnants of this, although there are many remnants in this area. From various considerations, such as age, type and distance, many of these remnants can be discounted and a "short-list" constructed. From new research suggesting a revised Σ-D relation, two remnants (G343.1-0.7 and G351.7+0.8) also appear to be suitable candidates although further research would be necessary to verify the remnant from SN393. Another record was found from Korea from the Middle Ages, although it is dubious whether this is a supernova (it is more likely a nova) and the position given for the guest star is perhaps too high to be a supernova.

Recently, a supernova remnant has been identified and is thought to be young in age. GRO/RX J0852 is thought to have exploded 700 years ago – the presence of certain radioactive isotopes indicates youth. However, there are no Chinese records of a guest star at this time – the supernova was extremely close to Earth (~150pc) and would have been brilliant. It is suggested that the political situation (the ruling Jin were at war with the Mongols) led to records either not being taken or being lost/destroyed. The astrophysical evidence is almost certain in dating the remnant and without any records, this is perhaps as far as historical-type research can lead.

Another remnant, G292.0+1.8 also appears to be young in age (1600 years) although no records exist for this supernova. This can be simply explained as the area of sky 292.0+1.8 is in is not visible in China.

The remnant IC443 has been long associated with a supernova in 837 through a positional coincidence between the remnant and a Chinese record. Although there is historical evidence to suggest this is the remnant of a supernova in 837, there is strong astrophysical evidence to suggest that the remnant is nearer 30,000 rather than 2000 years old. This uncertainty is due to physical anomalies between the gaseous area of the remnant and the associated pulsar – the observed characteristics of the pulsar do not indicate and age of 30,000 years, although it has been suggested that our current pulsar models may be incorrect. It is concluded that further astrophysical research is required before a definite link can be given.

Other historical supernovae have been considered for completeness, although given the extent of research into these, there is no reason to doubt the association, or to suggest other, remnants for these supernovae.

It is unlikely that new and relevant records will be found, and as such, the only avenue of investigation is through improved observations and remnant models. However, given the dependence of developing models on historical research, it may be some time before the association of remnants with records can definitely be confirmed beyond doubt.

APPENDIX I

Supernova Remnants in the Scorpius Region

Remnants between $l = 0°$ and $l = 340°$ at low galactic latitudes:

Remnant	Type	Distance	Green*
G340.4+0.4	Shell		193
G340.6+0.3	Shell		194
G341.2+0.9	Composite?		195
G341.9-0.3	Shell		196
G342.0-0.2	Shell		197
G342.1+0.9	Shell		198
G343.1-2.3	Composite?		199
G343.1-0.7	Shell		200
G344.7-0.1	Shell		201
G345.7-0.2	Shell		202
G346.6-0.2	Shell		203
G347.3-0.5	Shell?		204
G348.5-0.0	Shell		205
G348.5+0.1 (CTB37A)	Shell		206
G348.7+0.3 (CTB37B)	Shell		207
G349.2-0.1	Shell		208
G349.7+0.2	Shell	18.3 ± 4.6 kpc	209
G350.0-2.0	Shell		210
G351.2+0.1	Composite?		211
G351.7+0.8	Shell		212
G351.9-0.9	Shell		213
G352.7-0.1	Shell		214
G354.1+0.1	Composite?		215
G354.8-0.8	Shell		216
G355.6-0.0	Shell		217
G355.9-2.5	Shell		218
G356.3-0.3	Shell		219
G356.3-1.5	Shell		220
G357.7-0.1	?		221
G357.7+0.3	Shell		222
G359.0-0.9	Shell		223
G359.1-0.5	Shell		224
G359.1+0.9	Shell		225

* This number refers to the number in David Green's SNR catalogue, numbered from the first remnant to last.

APPENDIX II

Guest Star Records Relating to the Supernova of 1006

Songshi, *Tianwen zhi*, ch.26
1006

"Emperor Zhenzong of Song, 3rd year of the Jingde reign period, 3rd month, day *yisi*. A guest star emerged in the southeast quarter."

Song huiyao jigao, ch.52
May 1st 1006

"Emperor Zhenzong of Song, 3rd year of the Jingde reign period, the 1st day of the 5th month. The Director of the Astronomical Bureau said 'Previously, on the 2nd day of the 4th month, during the first watch of the night, a large star was seen. It was yellow and it emerged east of *Kulou* and west of *Qiguan*. It grew brighter by degrees and was measured to be three *du* in *Di*."

Songshi, Tianwen zhi, ch.56
May 6th 1006

"Emperor Zhenzong of Song, 3rd year of the Jingde reign period, 4th month, day *wuyin*. A *zhoubo* star emerged south of *Di*, one du west of *Qiguan*. It was shaped like half a moon and had horned rays. It shone so brightly that one could see things in detail. It passed through the east of *Kulou*. In the 8th month it followed the celestial sphere and entered the horizon. In the 11th month, it was seen again in *Di*. From this time on, during the 11th month it was frequently seen in the east during the hour of *chen* and in the 8th month it entered the horizon in the southwest."

Songshi, Zhenzong san, ch.7
May 30th 1006

"Emperor Zhenzong of Song, 3rd year of the Jingde reign period, the 5th month, day *renyin*...a *Zhoubo* star appeared... In the 11th month, day *renyin* the *Zhoubo* star was seen again."

APPENDIX III

Record from chapter 6 of the Ming Shenzong Shilu of the Supernova of 1572AD

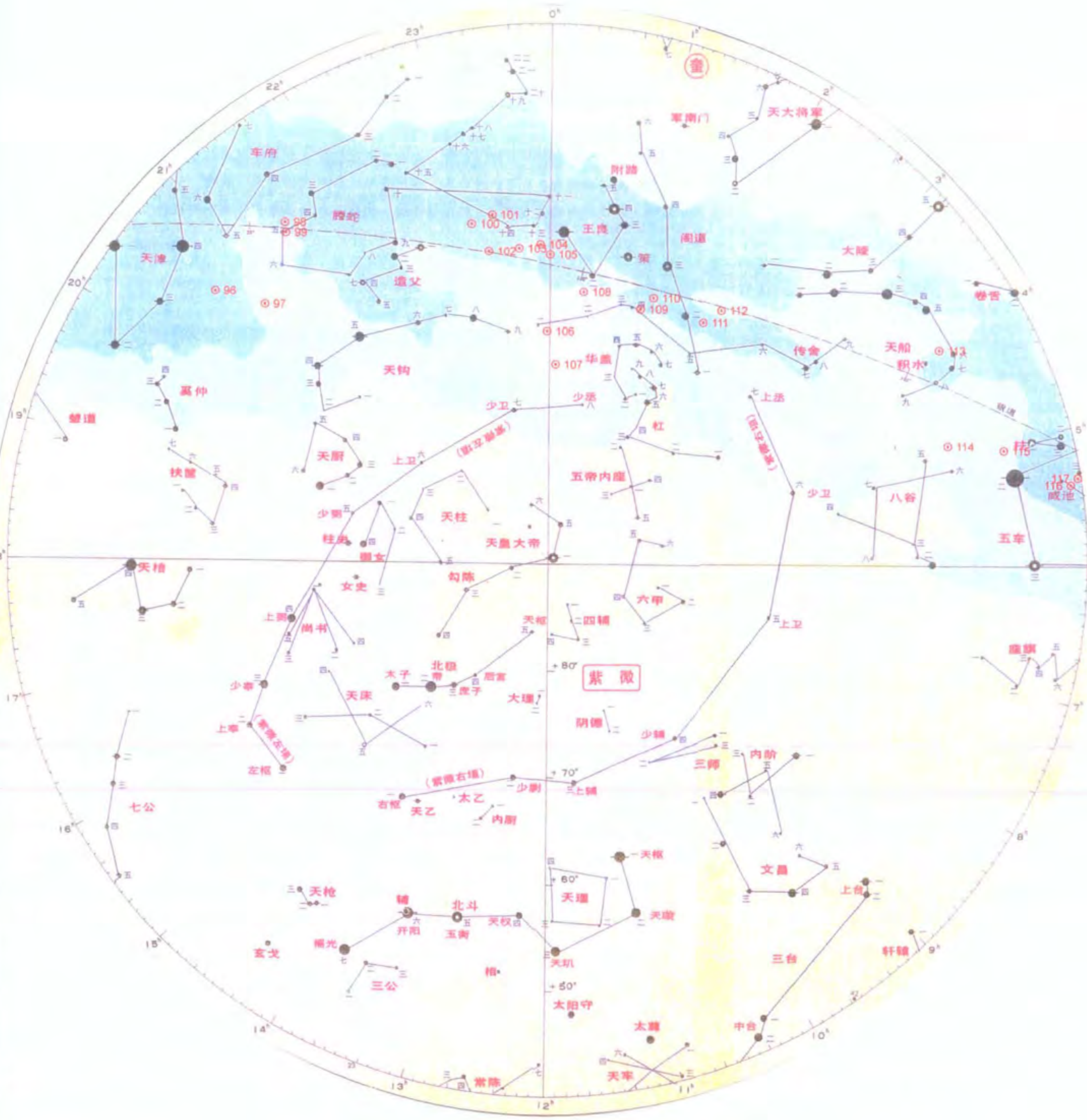
> "Longqing reign period, sixth year, 10^{th} lunar month, day *xinwei*... Previously, in the 10^{th} lunar month, 3^{rd} day *bingchen* at night a guest star was seen at the northeast direction. It was like a crossbow pellet. It appeared beside *Gedao* in the degrees of *Dongbi* lunar lodge. It gradually had small pointed rays and it was bright. On the 19^{th} day *renshen*, at night this star was reddish-yellow in colour. It was as large as a cup and its light rays were in the four directions. The standard interpretations say: 'This is a bushy star. It is sometimes seen before sunset'. The standard interpretations (additionally) say: 'It is also seen in the day'.
>
> "At this time the Emperor saw it with his officials and they were alarmed. He ventured out at night to pray at the Red Stairs. The officials, Zhang Juzheng and others, said that the lords and ministers all requested that all the officials inside and outside the palace should undergo rigorous self-examination. The Emperor sent an edict to the Board of Rites saying : 'This mysterious phenomenon is a sign of abnormal thing, I am greatly worried by this. All of the offcials inside and outside court should undergo rigorous self-examination.' Then they scrutinised previous precedents to decide how to act. The Board of Rites memorialised requesting that they go on the precedent of the 42^{nd} year of the Jiajing period [AD1563] when Mars moved backwards and forwards in sucession.
>
> "The officials all wore blue/green clothes and horned belts as they went about their business. On the 5^{th} day [November 10^{th} 1572] (the Emperor) announced: 'All of you officials should appreciate my intention in respecting Heaven's warning, and should whole-heartedly carry out your duties so that we may together eliminate this. Do not simply produce empty reports of your self-examination'."

Translation taken from Green & Stephenson (2002).

APPENDIX IV

Chinese Star Maps

The following maps are of Chinese asterisms with remnants from David Green s supernova catalogue also plotted. The remnants are numbered 1-225, starting at G0.0+0.0 and ending with G359.1+0.9. The remnants are denoted by a red circle with an associated number.



APPENDIX IV

Chinese Star Maps

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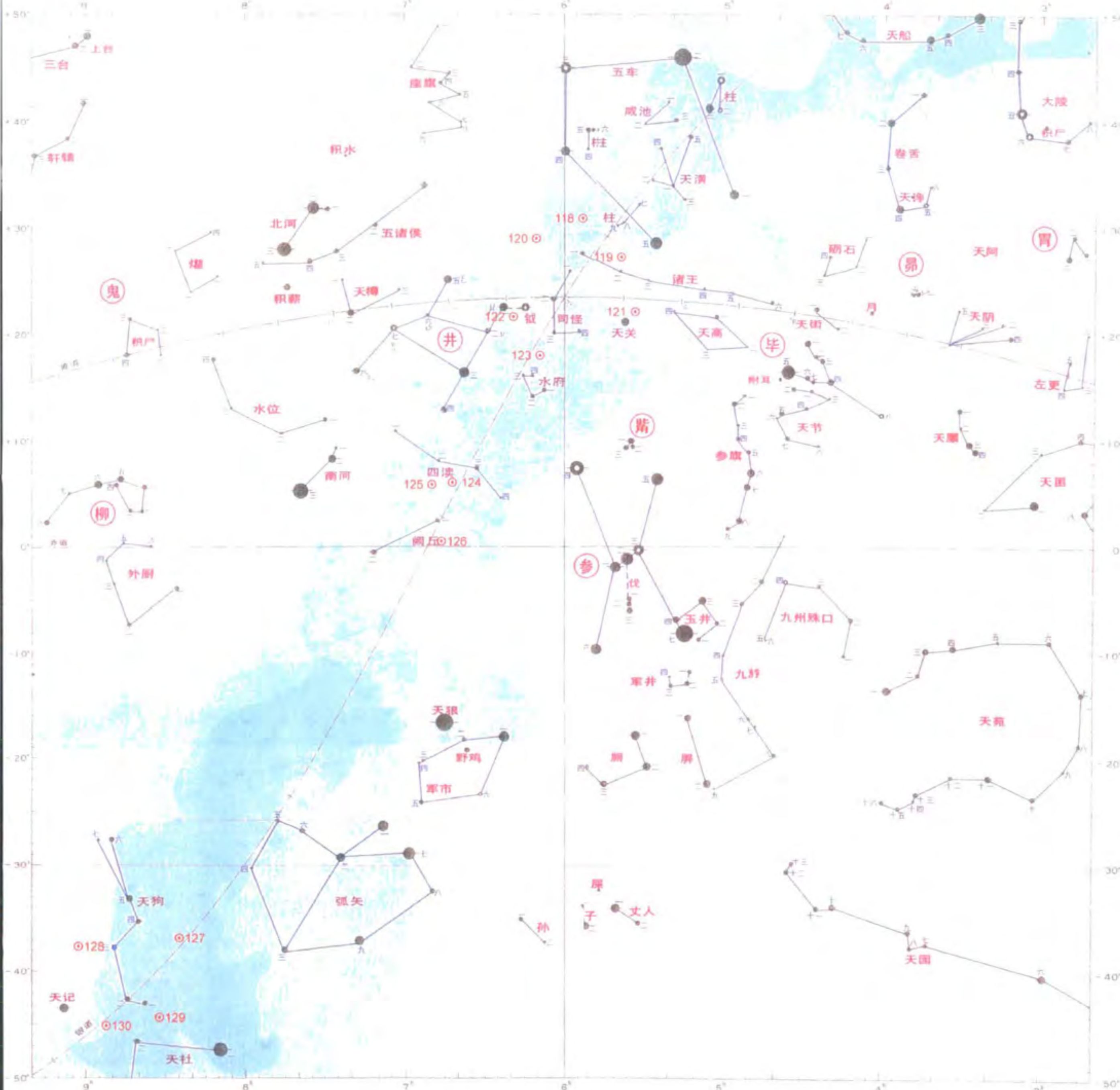
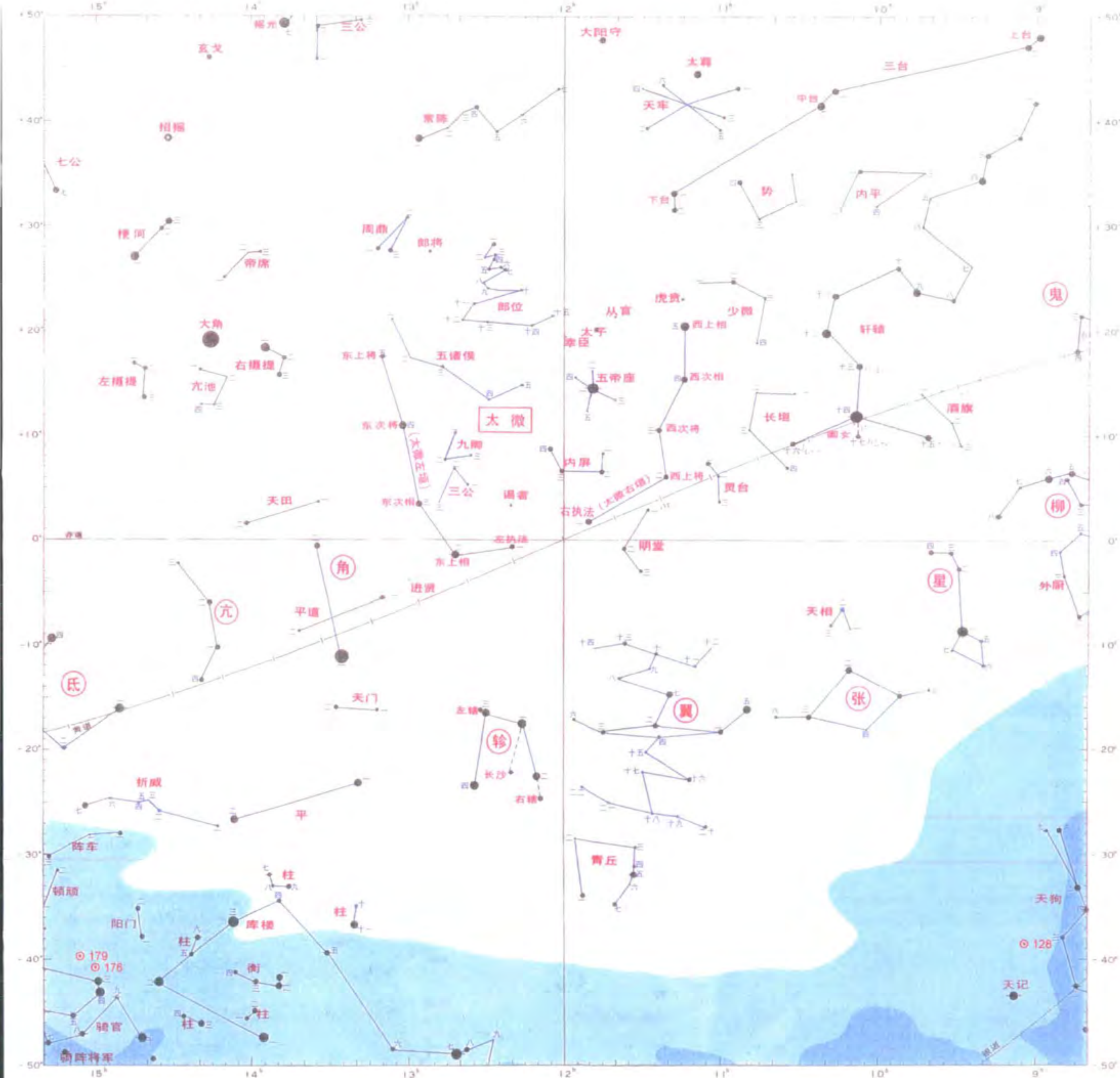
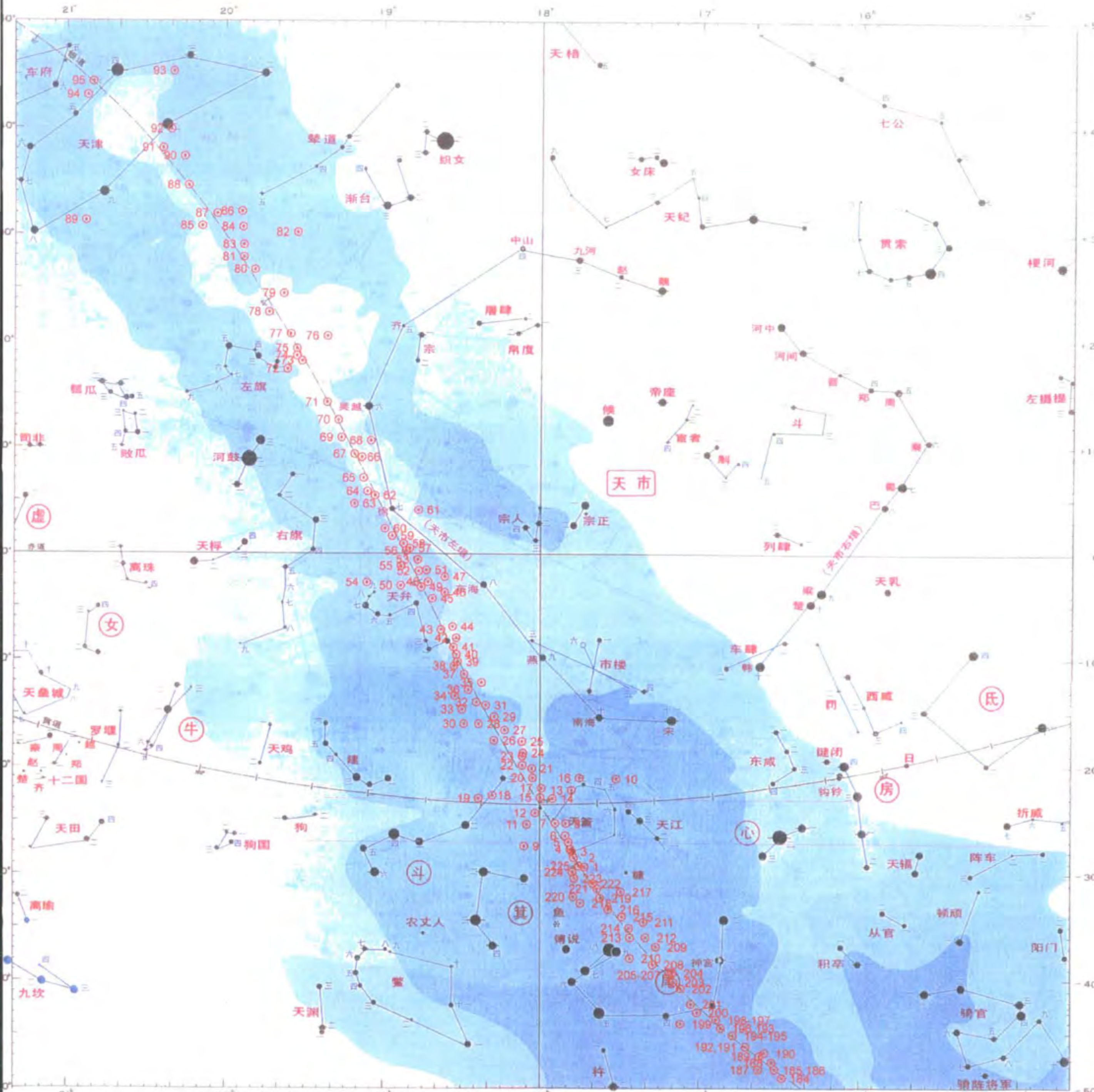
Chinese Star Maps



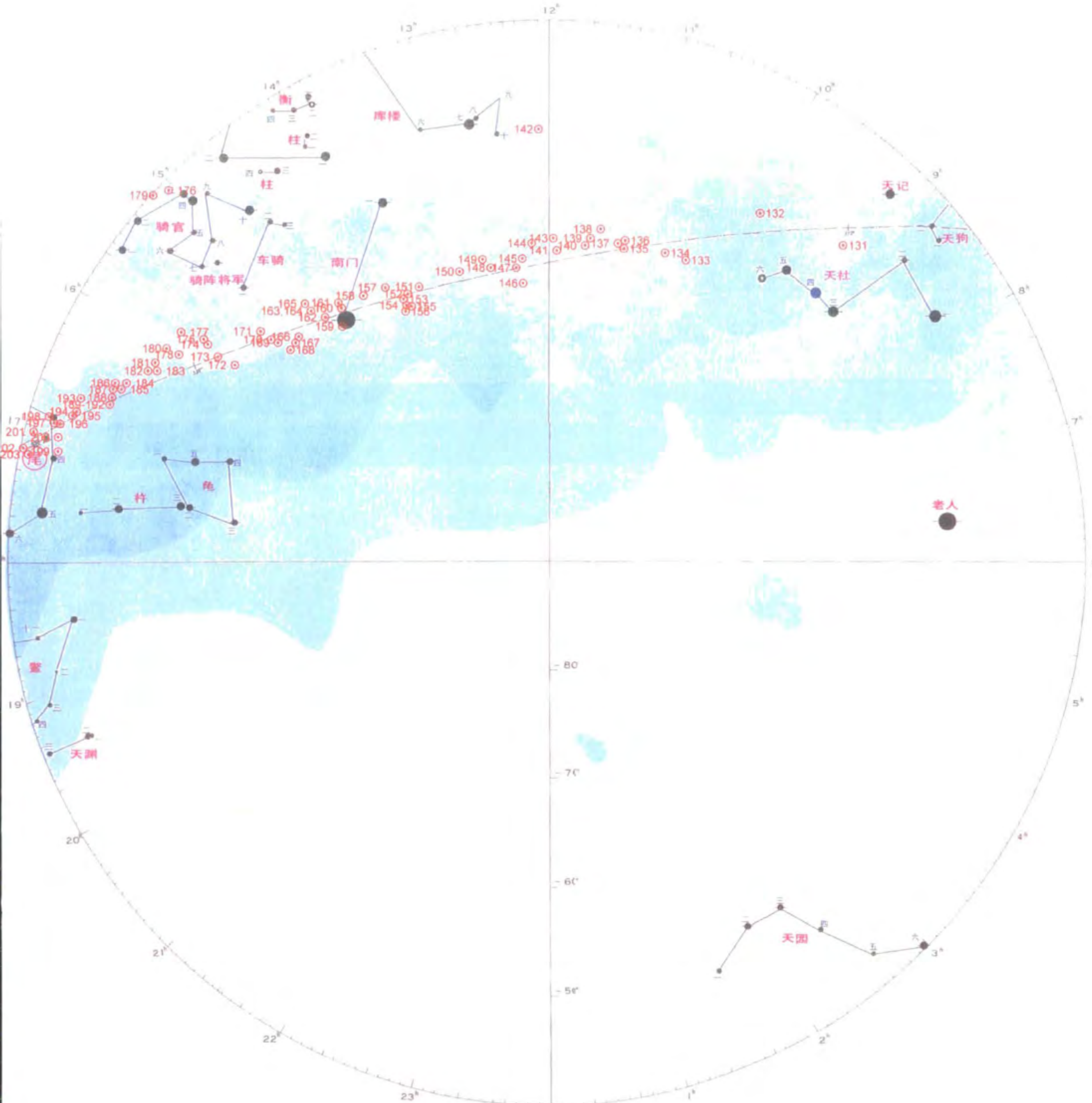
APPENDIX IV
Chinese Star Maps



APPENDIX IV
Chinese Star Maps



APPENDIX IV
Chinese Star Maps



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Journal abbreviations used:

A&A	*Astronomy & Astrophysics*
A&A Suppl.	*Astronomy & Astrophysics Supplement*
AJ	*The Astronomical Journal*
ApJ	*The Astrophysical Journal*
ApJ Suppl.	*The Astrophysics Journal Supplement*
J.Hist.Ast	*Journal for Historical Astronomy*
MNRAS	*Monthly Notices of the Royal Astronomical Society*
PASJ	*Publications of the Astronomical Society of Japan*
PASP	*Publications of the Astronomical Society of the Pacific*
QJ RAS	*Quarterly Journal of the Royal Astronomical Society*

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